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GUIDELINES FOR REARING CONTAINERIZED CONIFER SEEDLINGS IN THE PRAIRIE PROVINCES

L.W. CARLSON

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PREFACE

Rapidly expanding reforestation programs in the three Prairie Provinces have created a pressing need for a set of guidelines on rearing high-quality containerized conifer seedlings. A provisional rearing manual for use in British Columbia was prepared by Matthews (1971) shortly after the introduction of containerized seedling systems in Canada. This manual has since been supplemented by operational manuals for specific container types, but by and large, information on rearing container seedlings in the Prairies is scattered in bulletins, journal articles, and internal reports by various government and university research centers. The purpose of this publication is to assemble under one cover the fragmented, piecemeal information available and to distill the experience of the author gained through 8 years involvement in the theory and practice of growing containerized seedlings. Although the guidelines are directed primarily at the greenhouse production of white spruce, lodgepole pine, and jack pine, it should be possible for the experienced production manager to apply the basic principles of rearing to other coniferous species.

Lester W. Carlson

PREFACE

Les programmes de reboisement qui progressent rapidement dans les trois provinces des Prairies ont créé un besoin urgent de lignes directrices sur la culture des semis en contenants de qualité supérieure. Un manuel provisoire pour la Colombie-Britannique a été préparé par Matthews (1971) peu après l'introduction au Canada des semis en contenants. Ce manuel a depuis été enrichi d'autres manuels appropriés à des types particuliers de contenants, mais la plus grande partie de l'information sur la culture des semis en contenants dans les Prairies est éparpillée ça et là dans des brochures, des articles de journaux et les rapports internes des divers centres de recherche des gouvernements et universités. La présente publication a comme objectif de réunir, sous une même couverture, les renseignements fragmentaires disponibles et de scruter l'expérience que l'auteur a pu accumuler au cours de 8 années consacrées à la théorie et à la pratique de la culture des semis conteneurisés. Bien que les lignes directrices soient principalement à l'intention des producteurs en serre d'Epinette blanche, de Pin tordu et de Pin gris, le gestionnaire producteur expérimenté devrait pouvoir facilement appliquer les principes fondamentaux de cette culture à d'autres espèces résineuses.

Lester W. Carlson

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NOTE

The exclusion of certain manufactured products does not imply rejection nor does the mention of other products imply endorsement by the Canadian Forestry Service.

INTRODUCTION

Container planting consists of growing seedlings in a suitable medium, such as peat, in some form of container and then outplanting the seedling plus the rooting medium. Short production periods, extension of the planting season, minimum planting shock, ease of handling, and economic competitiveness with conventional bareroot seedling systems are the main advantages of the method.

Over the past 13 years many different containerized systems have been developed for rearing conifer seedlings for reforestation programs. With each new system techniques changed, and in many cases the quality of seedlings improved. In fact, a new container often would be readily accepted in anticipation of attaining improved seedling growth. At the same time that containerized systems were evolving, our knowledge of seedling biology was also expanding, enabling us to improve seedling growth. The objective of these guidelines is to bring rearing practices into line with our basic biological knowledge.

The foreword to the "provisional" manual for containerized seedling production by Matthews (1971) admitted that no single ingredient in the rearing recipe could replace *TLC*—"Tender Loving Care." It is hoped that these guidelines will begin to define TLC. Growing conifer seedlings in containers is still somewhat of an art, and true art cannot be mass produced. Yet the need for mass production of seedlings is evident, so with some trepidation I attempt to make a scientific process out of an art form.

SEEDLING QUALITY

Before a prescription for the production of containerized seedlings can be given, the production goal must be defined. The goal should *not* be to produce a certain number of seedlings, but to produce quality seedlings having specific dimensions that can be monitored during the rearing process. Criteria to measure quality should include height, dry weight, stem diameter, and physical condition.

Height

At the end of a rearing period seedling height, as measured from the ground to the top of the terminal bud, will vary with species and length of rearing period (Fig. 1), and also rooting volume of the container (Fig. 2). The minimum acceptable height of seedlings grown in 40-cm^3 containers at the time of outplanting should be:

Species[1]	Height (cm)
Jack pine	8-10
Lodgepole pine	8-10
Red pine	9-12
White spruce	10-13
Black spruce	12-15
Colorado spruce	10-12
Douglas-fir	12-14

To attain these minimum acceptable heights for locally important species a rearing period of 20 weeks is required:

Species	Rearing period Weeks after germination		
	8	14	20
	Height (cm)		
Jack pine	4	8	10
Lodgepole pine	4	8	10
White spruce	5	10	13
Black spruce	5	12	15
Douglas-fir	4	9	12

Dry Weight

Several measures of seedling quality can be derived from ovendry weight measurements (seedlings dried in paper bags for 24 h at 85°C). The total dry weight of the ideal seedling ready for outplanting in the Prairie

[1] Jack pine (*Pinus banksiana* Lamb.); lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.); red pine (*Pinus resinosa* Ait.); white spruce (*Picea glauca* (Moench) Voss); black spruce (*Picea mariana* (Mill.) B.S.P.); Colorado spruce (*Picea pungens* Engelm.); and Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco).

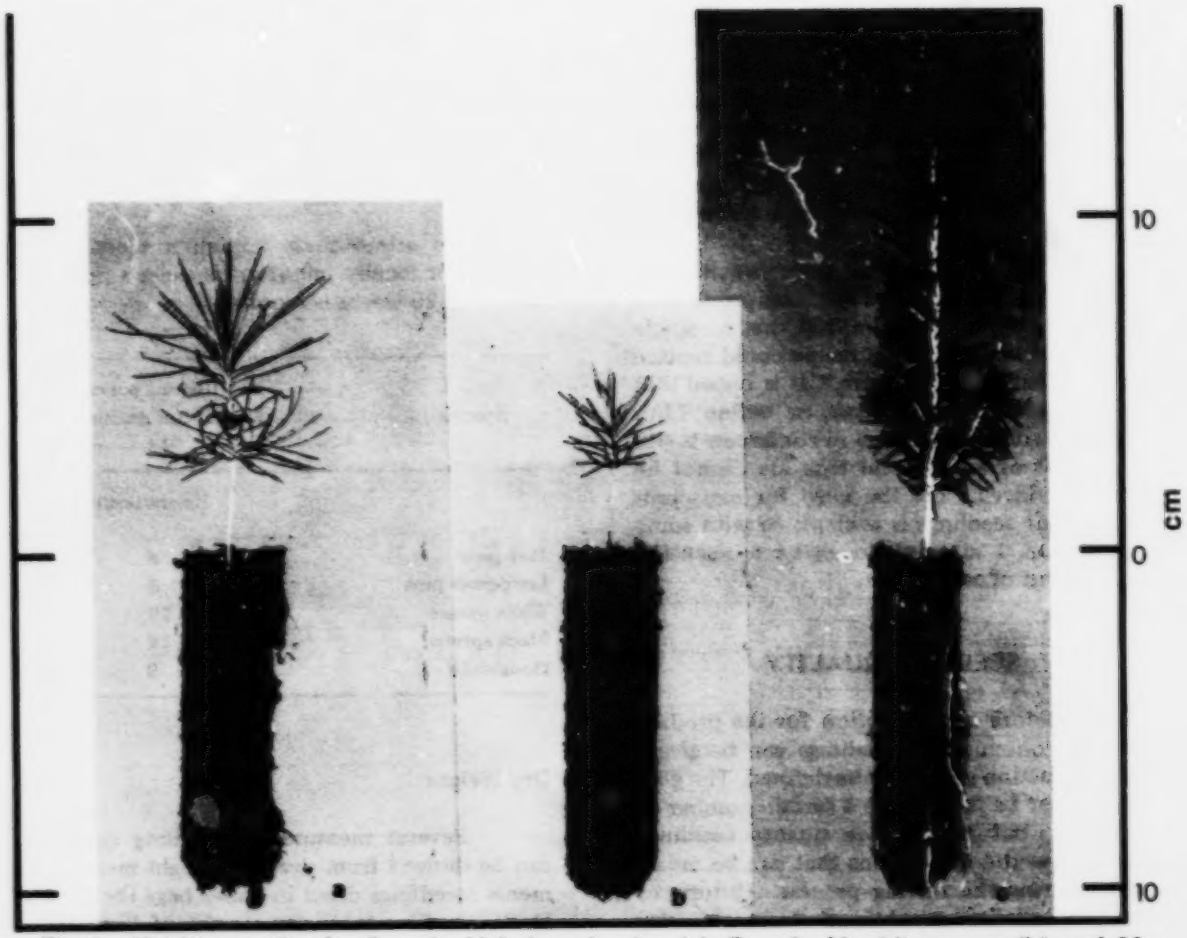

Fig. 1. Height growth of a 7-week-old lodgepole pine (a), 7-week-old white spruce (b), and 20-week-old white spruce (c). All seedlings were grown in Spencer-Lemaire (Ferdinand) containers.

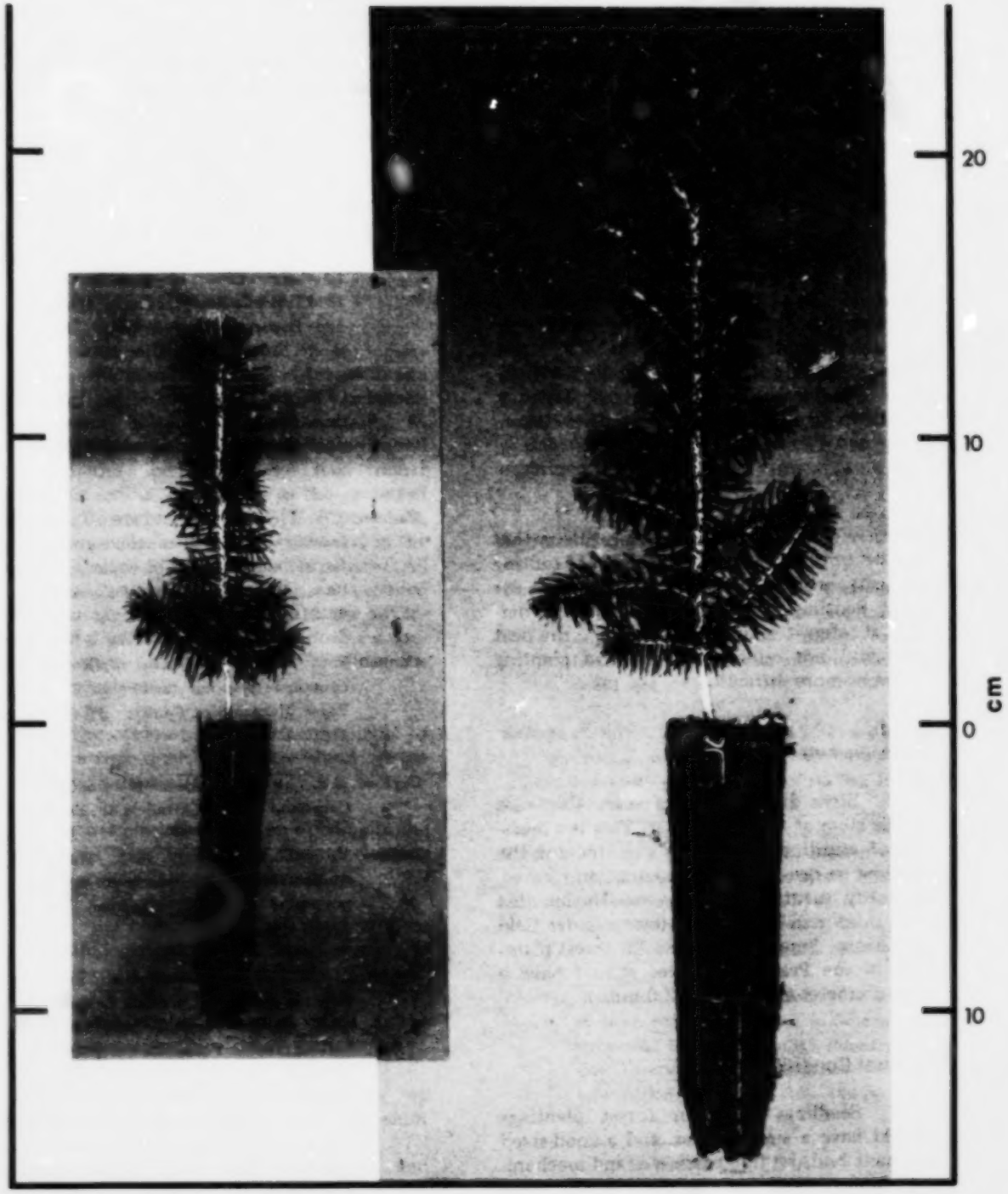

Fig. 2. Height growth of white spruce seedling after 20 weeks in a 35-cm^3 cavity (BC/CFS Styroblock 2, left) and a 115-cm^3 cavity (BC/CFS Styroblock 8, right).

Provinces should exceed 1000 mg for species of pine and 750 mg for spruce and other conifers. The shoots of pine should have a dry weight greater than 670 mg and of spruce greater than 565 mg. The roots should weigh more than 330 and 185 mg respectively. Shoot:root ratios should not exceed 2:1 for pine species or 3:1 for spruce species.

	Ideal seedlings	
	Pine species	Spruce and other conifers
	Ovendry weight (mg)	
Shoot	670	565
Root	330	185
Total	1000	750
Shoot:root ratio	2:1	3:1

Another parameter for measuring quality that can be obtained from dry weights is rooting intensity, which is the dry weight of roots per cubic centimetre of rooting volume. Generally, at intensities under 4.0 mg/cm^3, the peat plug will not retain its form, and planting becomes more difficult.

Stem Diameter

Stem diameter refers to the thickness of the stem at the root collar. This is a measure of sturdiness, which is essential for the seedling to resist crushing by grass and leaves. A sturdy plant can also be rapidly handled with minimum mechanical injury under field conditions. Pines and spruces for forest plantings in the Prairie Provinces should have a stem diameter greater than 2.0 mm.

Physical Condition

Seedlings used for forest plantings should have a single leader, and a good-sized dormant bud, be free of disease and mechanical damage, and have a good green color without any nutrient deficiency symptoms. Special attention should be given to checking for mechanical damage, by which is meant any type of injury caused by equipment or improper rearing practices. The most frequently occurring problem is winter browning of overwintered stock caused by inadequate snow cover or lack of protection from desiccation by late winter and early spring winds.

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TYPES OF CONTAINERS

Many different types of containers (Fig. 3) were manufactured and tested in the first 10 years (1966-76) in which containerized seedling programs were developing. In the Prairie Provinces only the Japanese paperpot and the Spencer-Lemaire root trainer remain in serious contention as the preferred system. However, the BC/CFS Styroblock, used extensively on the west coast and in the western United States, is still competitive. All containers, even the presently abandoned ARC sausage and Ontario tube, have advantages and disadvantages. When choosing a container system, the grower must consider the following points:

1. Are the optimum cavity sizes available to give a high-quality seedling based on the chosen prescription?
2. Does the container have an opening in the bottom large enough to prevent clogging with roots as air pruning occurs?
3. Does the container have vertical grooves continuing right to the bottom opening to direct roots to the bottom?
4. Does the container gently curve to the bottom opening?
5. Is the container package ready for use or must it be assembled?
6. Do containers easily fit into an efficient operational system?
7. Does the container readily lend itself to distribution in the field?
8. Can the container be easily carried by the planters?
9. Is the seedling easily removed?
10. Is the container reusable?
11. Can the containers be handled on pallets that can be recycled from the planting site?
12. How much does the container cost?

The ultimate selection of a container or containerized system must depend on the needs of the particular seedling production program chosen and on the expected final product; for example, large containers yield larger seedlings. The major types of containers currently in use in the Prairie Provinces are described in Table 1 and illustrated in Fig. 4.

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Carlson, L.W. and F. Endean. 1976. The effect of rooting volume and container configuration on the early growth of white spruce seedlings. Canadian Journal of Forest Research 6:221-224.

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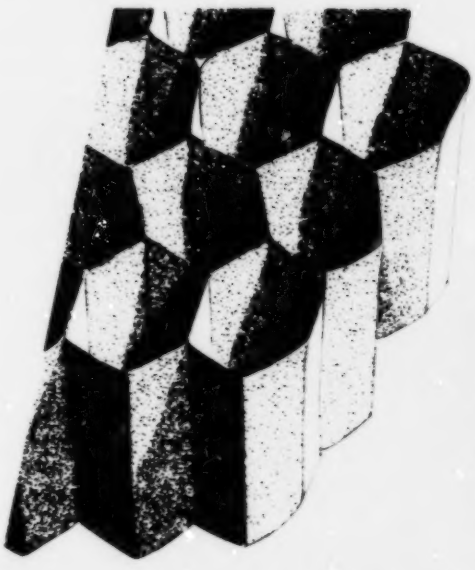
Waldron, R.M. (Ed.). 1972. Proceedings of a workshop on container planting in Canada. Environment Canada, Canadian Forestry Service, Directorate of Program Coordination. Information Report DPC-X-2. 168 pp.

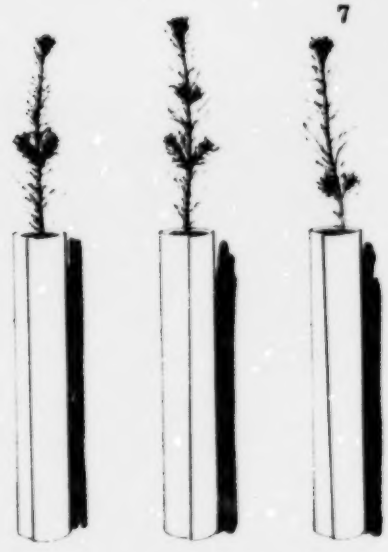
GROWING MEDIA

The selection of the growing medium for the containerized seedling is a crucial step. The container used, ease of loading the med-

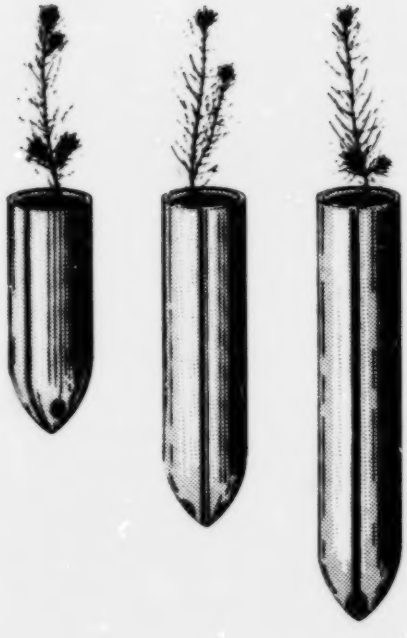
Fig. 3. Containers used or tested in Canada between 1966, when container systems became operational, and 1972 (after Waldron 1972). Some containers, such as the BC/CFS Styroblock, Japanese paperpots, and Spencer-Lemaire root trainer, have since undergone modification.



Japanese paperpots



Ontario 9/16" tube



Walter's bullets

Spencer-Lemaire root trainer

Table 1. Major container types currently in use in the Prairie Provinces

Type of container	Tray size (cm)	Cavities per tray	Cavity volume (cm^3)	Nominal cavity size: Rectangular containers Length x width x height (cm)	Nominal cavity size: Cylindrical containers Diameter x height (cm)
Spencer-Lemaire					
Ferdinand	22 x 37	102	40	1.9 x 1.9 x 10.1	
Five	22 x 37	70	55	2.5 x 2.5 x 10.1	
Hillson	22 x 37	32	150	3.8 x 3.8 x 12.7	
Tinus	29 x 47	40	500	5.1 x 3.8 x 18.4	
Super 45	29 x 47	27	700	6.3 x 5.1 x 22.8	
BC/CFS Styroblock					
2	35 x 52	192	35		2.4 x 11
2A	35 x 60	240	35		2.4 x 11
4	35 x 60	160	60		4.9 x 12.5
8	35 x 52	80	115		3.8 x 15
20	35 x 60.5	45	330		5.9 x 15
Japanese paperpot					
308	32 x 94	532	44		3.0 x 7.6
315	32 x 94	532	88		3.0 x 15.2
408	35 x 94	336	70		3.8 x 7.6
415	35 x 94	336	140		3.8 x 15.2
508	37.5 x 90	420	121		5.1 x 7.6
515	27.5 x 90	420	242		5.1 x 15.2
608	39 x 181	280	175		6.1 x 7.6
615	39 x 181	280	350		6.1 x 15.2

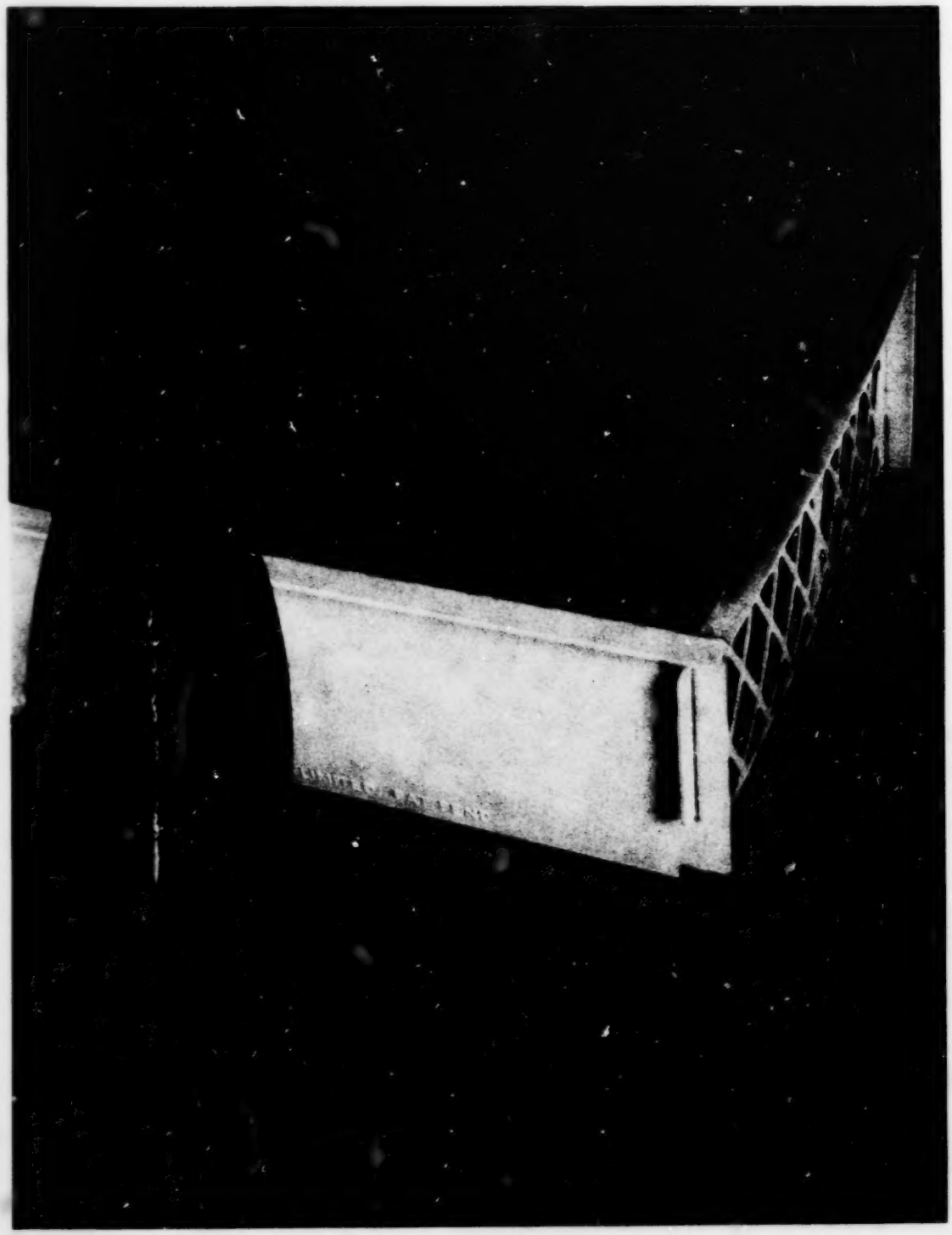


Fig. 4. Containers currently in common use in the Prairie Provinces, with 20-week-old white spruce seedling (Scale: 1 cm = 2 cm). Spencer-Lemaire (Ferdinand). . .

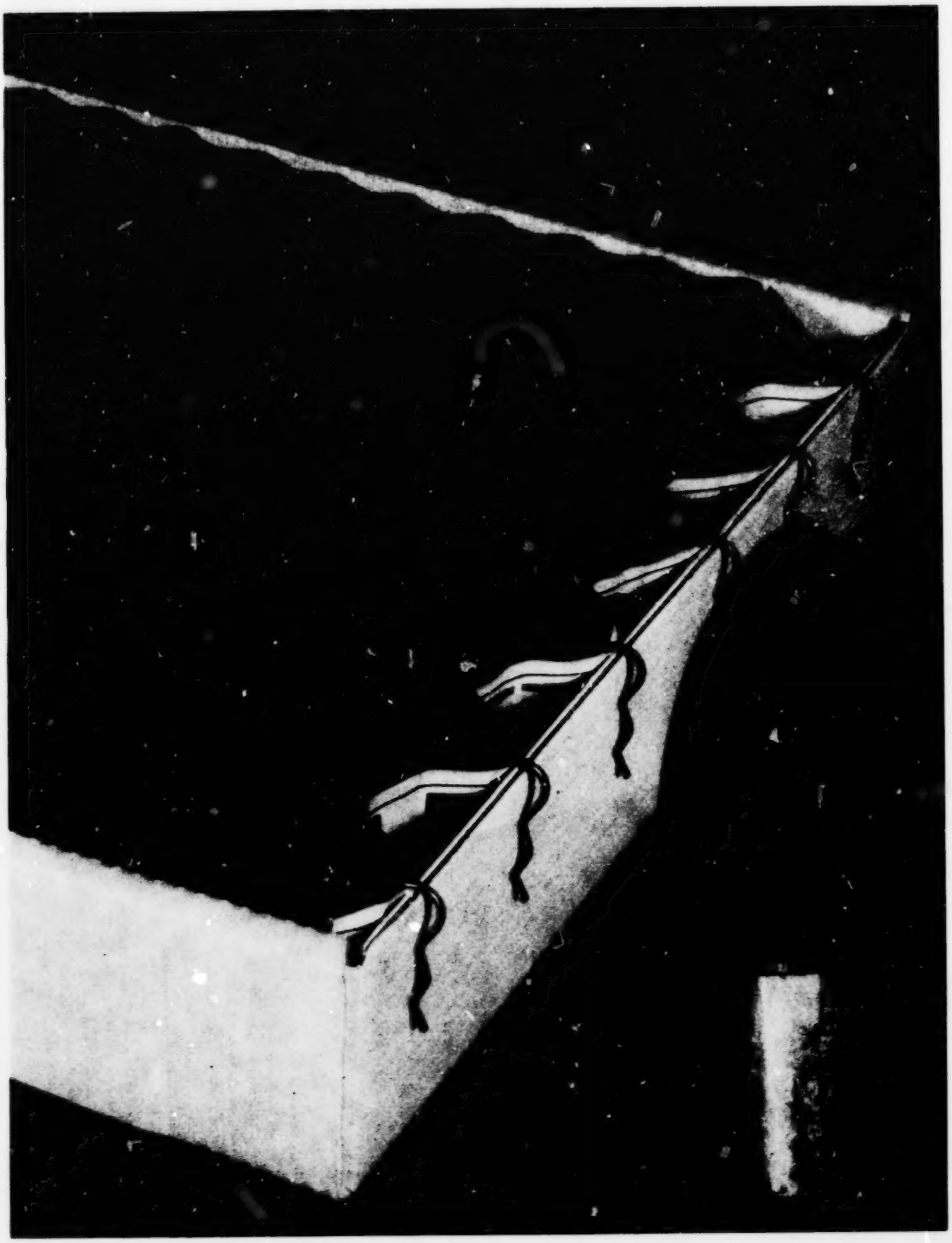


Fig. 4 (cont.). Japanese paperpot 408. . .

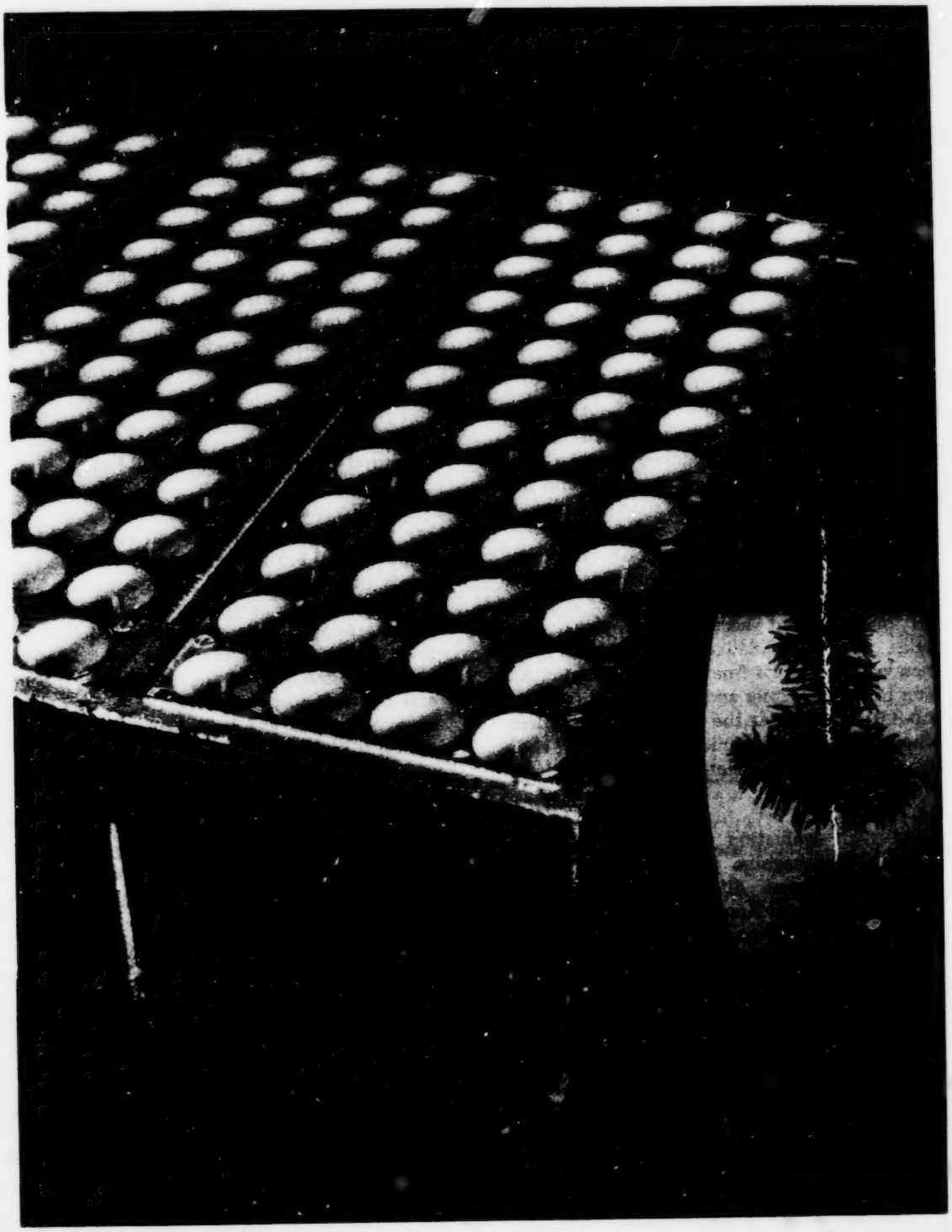


Fig. 4 (concl.). and BC/CFS Styroblock 2.

ium into the cavities, and source of the medium must be considered. The latter is important for ensuring consistency between production runs. The growing medium must be porous enough to allow water and nutrients to drain properly and to allow seedling roots to develop, yet compact enough to retain some of the same water and nutrients and to resist drying out. A chemical and physical analysis of the medium prior to use is advisable.

Peat

In the Prairie Provinces sphagnum peat is the most widely used and recommended medium for growing conifer seedlings in containers. It can be packed into the cavities, giving both the porosity needed and the water- and nutrient-holding capacity required. The pH may range from 4.0 to 5.5. However, as sphagnum peat ages in the bogs it decomposes, becoming more humified. This reduces porosity and increases the problems of high pH and nutrient accumulation much like sedge peat does. Sedge peat is not recommended because its fine fiber causes compaction in the container and the high pH (around 7.0-8.0) exacerbates the compaction problem when nutrients are applied. When the pH rises above 6.0 both nutrient and weed problems are increased.

An evaluation of five commercial brands[2] of sphagnum peat from the Prairie Provinces showed differences in seedling growth. Each peat brand should therefore be tested for pH and coarse:fine ratio and then modified to meet the standards set out in Table 2 before use. It was also noted that even with these modifications slight changes in the rearing schedules were required for each brand in order to achieve the optimum growth of pine and spruce.

Peat and Vermiculite

The use of a peat-vermiculite mixture is standard practice in B.C. Forest Service nurseries, at several industrial nurseries in Alberta, and in many U.S. container programs. The mixture developed by the Pacific Forest Research Centre in Victoria has a ratio of 3 parts peat to 1 part horticultural grade vermiculite. This has the advantage of weighing only half of the suggested California "U.C." sand-peat mixture and being more easily mixed. It also has a greater water-holding capacity than either pure peat or a peat-sand mixture. However, this is not totally advantageous, because drainage may be impaired, and proper flushing out of old nutrients or staling products may thus become difficult. Accumulation of nutrients and the lack of drainage lead to increased pH levels and reduced seedling growth.

Required Chemical Properties of Peat

To maximize conifer seedling growth, the pH of the medium should be maintained at about 5.0-5.5 and not allowed to increase much higher. This level may be attained by using a source of peat with the desired pH or by increasing it by adding lime or decreasing it by adding sulphur. The pH is maintained by regulating the pH of the nutrient solutions and the irrigation water. These methods will be explained in the sections on Seedling Nutrition (page 28) and Irrigation (page 34).

Not much is known about other specific chemical properties of peat required for containerized conifer seedling rearing; however, the maximum tolerable chemical conditions in a medium that will give good seedling growth are

Chemical property	Range required[1]
Hydrogen-ion concentration (pH)	4.5-5.5
Electrical conductivity (EC)	<0.50 mS/cm
Cation exchange capacity (CEC)	85-160 meq/100 g
Exchangeable sodium (ES)	<10%

[1] See Appendix 1 for explanation of units used.

These conditions should be checked in each batch of peat before it is used.

[2] Brands tested: Alberta Rose, Canada Brand, Emerald, Green Thumb, and Sunshine.

Table 2. Physical characteristics of peat from the Prairie Provinces and acceptable standards of peat quality

Physical characteristics	Peat source[1]				Acceptable standards
	1	2	3	4	
Saturated weight (g/L)	718	735	660	685	600-900
Dry weight (after saturation) (g/L)	58	94	64	73	<100
Ash content (%)	4.3	9.0	8.0	9.1	<10
Bulk density (g/mL)	0.054	0.088	0.060	0.068	<0.120
Specific gravity (g/mL)	1.53	1.56	1.56	1.56	--
Pore volume (%)	96	94	96	96	--
Water capacity by volume (%)	62	60	56	57	>50
Air capacity (%)	35	34	40	38	>34
Coarse:fine ratio	0.34	0.17	0.34	1.60	>0.50

[1] Listed alphabetically, brands tested were Alberta Rose, Emerald, Green Thumb, and Sunshine.

Required Physical Properties of Peat

The physical properties of peat that promote growth of conifer seedlings in containers have not been well defined. However, knowing the peat quality can at least help reduce variability in the container program, because there are differences in peat quality within each bog depending on the depth at which the peat is harvested. The physical properties used for characterizing peat are (1) ash content, (2) bulk density, (3) specific gravity, (4) pore volume, (5) water capacity, (6) air capacity, and (7) coarse:fine ratio. These determinations can be made in a small laboratory using the procedures described in the following section; they should be done on each batch of peat before it is used. The range of physical peat characteristics that can be expected in the Prairie Provinces and acceptable standards of peat quality are shown in Table 2.

Techniques for Measuring the Physical Properties of Peat

A. Equipment and materials required:

1. A balance to weigh up to 2000 g with an accuracy of ±0.1 g.

2. A drying oven capable of heating to 105°C. In lieu of an oven, a cone-drying kiln area can be used to air-dry peat samples.

3. A muffle furnace capable of producing temperatures between 400 and 700°C. Ashing of samples can also be done in makeshift containers over a gas stove if the containers are constructed to eliminate convection currents.

4. Five cylindrical containers with perforated bottoms, 10 cm (±0.5 cm) in height

and at least 12 cm in diameter. It is necessary to know the volume of the containers.

$$V = \frac{\pi HD^2}{4}$$

Where: H = height in cm
D = diameter in cm
π = 3.14 [3]

5. A flat basin with overflow holes in the side 1 cm from the bottom. This basin should be able to hold the five containers side by side.

6. An overhead misting unit to give equal coverage of the five containers.

B. Procedures:

1. A 1-L sample of the peat to be tested is weighed, air-dried for 24-48 h, and reweighed. A portion of it is ashed at 400°C for 6 h (or 3 h at 700°C) and reweighed.

2. Approximately 10 L of peat is premoistened to bring the moisture content to 200% of the initial dry weight. That is, if the initial dry weight (air-dried) of 1 L of peat is 100 g, bring the total premoistened weight of 1 L of peat to 300 g. All five cylindrical containers are filled with the loose, premoistened peat with care not to compress it. The containers are then placed in the flat basin, which automatically maintains a free water level of 1 cm (Fig. 5). The basin and containers are placed under a misting system for 24 h. The containers are then covered to prevent evaporation and kept standing in free water for an additional 48 h. After being removed from the basin and allowed to drain for 2 h, the containers are weighed, and the saturated weight of the peat is determined. Next, the peat is removed from each container and dried for 24-48 h, either in an oven or in the open air, and the dry weight, after saturation, is obtained.

3. Sieve a sample of the air-dried peat from the batch to be used through a 2-mm sieve and weigh the amount passed and the amount retained.

C. Calculation of peat standards:

From the measurements taken in B.1. above:

1. Initial water content of the peat (%) =

$$\frac{\text{initial weight (g)} - \text{initial dry weight (g)}}{\text{initial dry weight (g)}} \times 100$$

2. Ash content (%) =

$$\frac{\text{ash weight (g)}}{\text{initial dry weight (g)}} \times 100$$

From the measurements taken in B.2. above:

3. Bulk density (g/mL) =

$$\frac{\text{dry weight after saturation (g)}}{\text{volume of peat sampled (mL)}}$$

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[3] For the calculations of bulk density and specific gravity to follow, volume of peat should be converted from cubic centimetres to millilitres. 1 cm^3 = 1 mL.

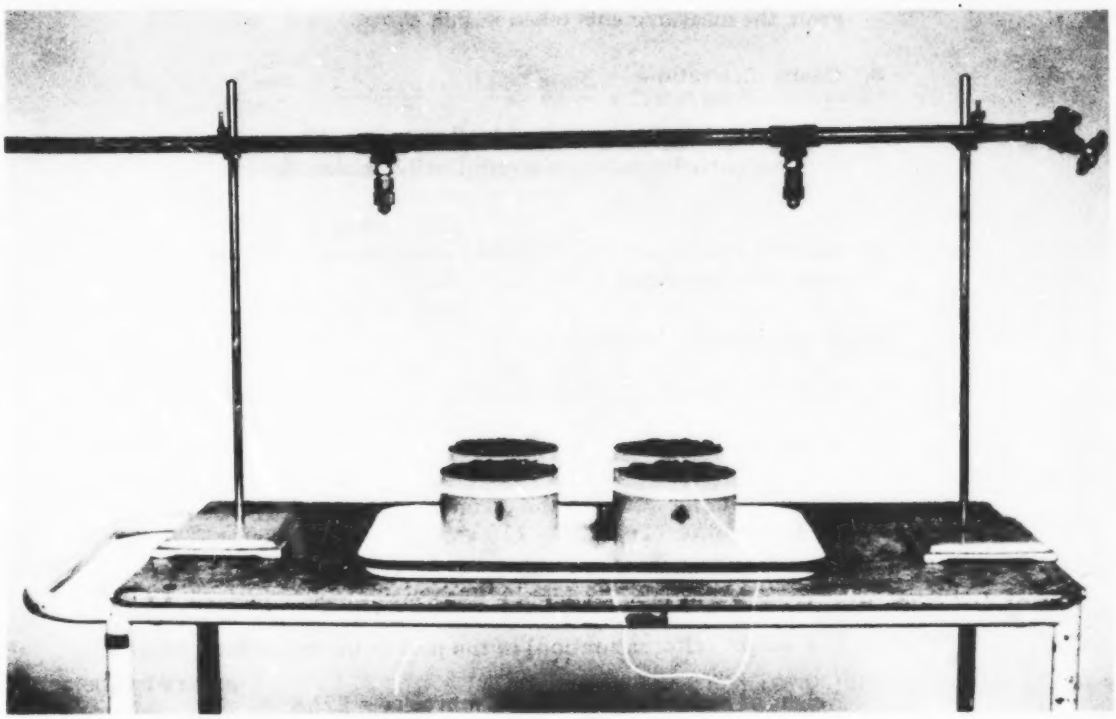

Fig. 5. Misting system and 1-cm deep basin to ensure a standard moisture content in peat before sampling to determine physical properties.

4. Specific gravity (g/mL) =

$$\frac{4.05}{1.2(n) + 1.5}$$

$$\text{Where } n = \frac{\text{initial dry weight (g) - ash weight (g)}}{\text{initial dry weight (g)}}$$

5. Pore volume (%) =

$$\frac{\text{specific gravity (g/mL) - bulk density (g/mL)}}{\text{specific gravity (g/mL)}} \times 100$$

6. Water capacity by volume (%) =

$$\frac{\text{saturated weight (g) - dry weight after saturation (g)}}{\text{weight (g) equivalent of water in the sample container}} \times 100$$

7. Air capacity (%) =

pore volume (%) - water capacity (%)

From the measurements taken in B.3. above:

8. Coarse:fine ratio =

$$\frac{\text{peat particles retained by 2-mm sieve (g)}}{\text{peat particles passing through the 2-mm sieve (g)}}$$

D. Examples based on actual measurements of peat characteristics and representing the average of five 1-L samples:

Initial weight = 190 g

Initial dry weight (air-dried) = 100 g

Ash weight = 4 g

Weight of water added to the premoistened peat to bring the moisture content to 200% = 110 g

Saturated weight of the peat in the container = 635 g/L

Dry weight (after saturation) of the peat in the container = 94 g/L

Weight of peat retained by the 2 mm sieve = 225 g

Weight of peat passing through the 2 mm sieve = 275 g

Container volume = 1 L or 1000 mL (note that 1 mL of water weighs 1 g)

The derived physical properties of the peat are

1. Initial water content of the peat (%) =

$$\frac{190\text{ g} - 100\text{ g}}{100\text{ g}} \times 100 = 90$$

2. Ash content (%) =

$$\frac{4\text{ g}}{100\text{ g}} \times 100 = 4$$

3. Bulk density (g/mL) =

$$\frac{94\text{ g}}{1000\text{ mL}} = 0.094$$

4. Specific gravity (g/mL)

$$n = \frac{100\text{ g} - 4\text{ g}}{100\text{ g}} = 0.96$$

$$\text{S.G.} = \frac{4.05}{1.2(0.96) + 1.5} = 1.53$$

5. Pore volume (%) =

$$\frac{1.53 \text{ g/mL} - 0.094 \text{ g/mL}}{1.53 \text{ g/mL}} \times 100 = 93.8$$

6. Water capacity by volume (%) =

$$\frac{635 \text{ g} - 94 \text{ g}}{1000 \text{ g}} \times 100 = 54.1$$

7. Air capacity (%) =

$$93.8 - 54.1 = 39.7$$

8. Coarse:fine ratio =

$$\frac{225 \text{ g}}{275 \text{ g}} = 0.82$$

According to criteria established in Table 2, the peat sampled is suitable for use in a container seedling program.

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LOADING CONTAINERS WITH PEAT

This is the first operation in getting the container program under way and also one of the most important steps in the entire program. As with any mass production system, quality control is extremely important; variances in loading will show up in an end product that isn't uniform.

Preparation of the Peat

Before the peat can be used it must be screened with mesh about 1-1.5 cm to remove sticks and large lumps. If the water content is over 200% the peat is difficult to screen. Most commercial peat is dried (naturally or by heat) and stored in 113-170 dm^3 (4-6 ft^3) bags. The removal of water is important in reducing shipping costs. Even at that the peat contains 150-200% water on a dry weight basis. Screening can be done by hand or by a soil shredder. The advantage of the shredder is that no special care has to be taken to re-

move sticks and pieces of wood, because they are ground into usable fragments.

The peat then has to be moistened to about 300% water content on the dry weight basis. This saturation is usually determined by squeezing the moistened peat; when free water can be obtained, the peat is assumed to have the proper moisture content for loading into the containers. If the moisture content is too low the peat is spongy and difficult to pack in the containers, and when water is added later in the rearing process the peat will settle considerably, reducing the effective volume of the containers. However, if the peat is too wet during loading, it tends to pack too tightly, eventually causing drainage problems. The moisture content of the peat will also be related to the filling method. For hand loading, the peat should be fairly moist to wet; for machine loading a somewhat drier peat is more easily handled. Experience alone will define the ideal moisture content for these two methods.

If the peat is very dry, it may be difficult to moisten. The use of a wetting agent (surfactant) in the water and/or warm water should alleviate this problem. Directions for use of the soil wetting agents are usually included on their containers; different compounds have different wetting properties.

Methods of Loading

Depending on the type of operation used at the nursery, the containers (cavities) may be loaded by hand or by machine. The simplest and slowest method is the former. Peat is poured over the cavities, the containers are shaken or banged until the peat falls in, and then the peat is finger packed. This is done several times until the cavities are filled to within 1.0 cm of the top and have the proper tightness. When the peat is properly packed, a testing procedure involving a close-fitting piston loaded with 300-400 g of mass (over a 6-cm^2 area) should just begin to compress the peat in the cavity; a 1 kg mass will depress the peat at least 5 mm but not more than 8 mm.

There are many variations of machine loading of cavities. Most systems combine cavity loading, seeding, and gritting in an assembly line operation. The systems include a hopper for feeding peat into the cavities, a vibrating table to facilitate complete filling and compaction, brushes to remove excess peat, a method of seed delivery, and a gritting system. The principles of operation of this basic system vary only slightly with the use of different container types. A combination of any of the machine stages and hand work can also be used.

Equipment for loading containers can be obtained directly from the developers of a particular system, or, with a little imagination and engineering know-how, the nurseryman can build his own. Those who are just starting up a container program should visit several existing production facilities for ideas on how to develop an automated system.

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SEEDING

Seed Handling

The health and care of seed are critical if the container operation is to be successful. The seed must be collected from the same general areas where the seedlings will be outplanted; extraction must be done with care not to injure the seed; the seed must be cleaned, sorted, and stored; and finally, the quality of the seed should be monitored frequently. Methods of collection and extraction vary from province to province and are described more appropriately in silvicultural and nursery operational manuals.

Seed Cleaning and Sorting

There are several ways seed can be cleaned and sorted. One of the more common methods is the use of the gravity table after the seed has passed through a vibrating sieve

seed cleaner (Fig. 6). The gravity table vibrates, allowing the heavier seed to move to one end of the table, while light (empty) seed and debris stay at the other end. Seeds are sorted by size and weight by collecting them at different intervals along the edge of the table (Fig. 7).

Another method is to use a column of air (Fig. 8) to separate the debris and different-sized seed. The air separation is convenient because it can handle smaller lots of seed than the gravity table and it is faster.

It has been suggested that only the heaviest 20% of the seed sorted should be used for seeding containers. While this technique ensures total germinative capacity, it may not solve the problem of uneven germination. It is recommended that heavy seed be used (80-90% fraction), but not the heaviest 10%, if even germination is desired. The other seed (0-80 and 90-100% fractions) can be used for bareroot production.

Seed Storage

Seed can be stored before or after the sorting depending on the proximity of the container operation to the bareroot production area and to the seed extraction facilities. However, storage of seed sorted to the prescribed weight groupings facilitates handling. Storage temperatures vary with different species; for example, pine can be stored successfully at -10 to -17°C, while spruce is better stored at 0 to -5°C. The moisture content of most conifer seed should be kept between 5 and 10% while in storage.

When the seeding operation is in progress only the amount of seed that can be reasonably used in one day should be removed from storage, and any seed not used at the end of the day should be returned. For this reason a household refrigerator should be part of the headerhouse equipment.

Seed Quality

The germinative capacity of the seed determines the ultimate success of the container program. This quality can be measured in several ways, most reliably by germinating a sample of seed from the seed lot in question. Germination tests are usually run on at least four replicates of 100 seeds each. While standard procedures are given in seed testing manuals, rough germination tests can be run in any room that has a northern exposure. Seed can be placed in a covered Petri dish with moist filter paper and left on the window sill for up to 28 d while the number of germinating seedlings is recorded. The temperature of the room should be approximately 20°C. Slight fluctuations in temperature will not invalidate the test.

Another test uses X-rays and Polaroid film. The seeds are soaked in solutions of a heavy-metal salt such as barium chloride. The heavy metal penetrates cracked and dead seed but not living tissues; therefore, the X-ray picture will show the dead areas as dark spots, making it easy to determine whether the seed is living or not. While this test is rapid, it does not indicate dormancy in seed.

The germinative capacity of each seed lot should be determined prior to storage and, within reason, just prior to seeding. Where lots are being stored for a long period they should be checked each year.

Preseeding Treatments

Under natural conditions conifer seeds may germinate over a period of 1 to 3 years. While this will ensure natural regeneration, it is hardly of any use to the nurseryman who needs close to 100% germination in a very short time. Delayed or nil germination makes it difficult to maintain production standards. The end result is extra cost in lost space or excessive thinning programs.

All preseeding treatments should increase germinative capacity and energy. With some seed the first step is to rupture or soften the seed coat to allow faster gas exchange and water uptake. Others may require rigorous stratification to alter dormancy. Just how the stratification affects the physiology of the seed is not entirely clear; however, the resultant increase in germination will cut costs and improve quality of the crop.

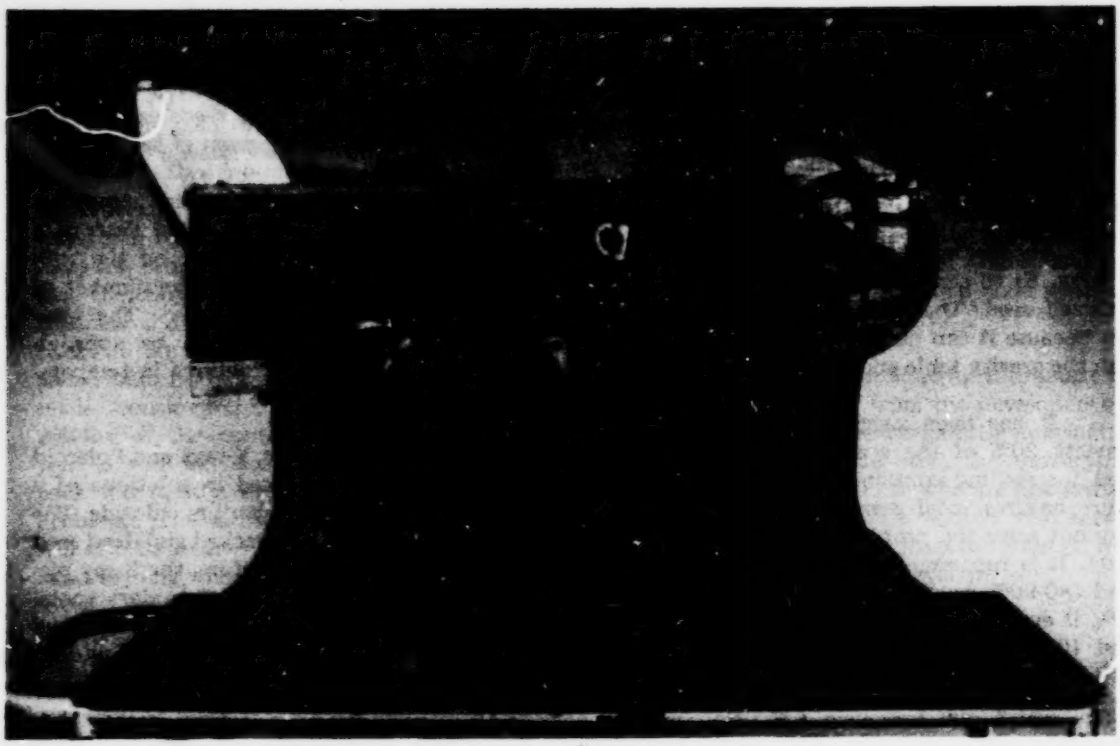

Fig. 6. Vibrating sieve seed cleaner.

Fig. 7. Gravity table used to separate seed by size and weight.

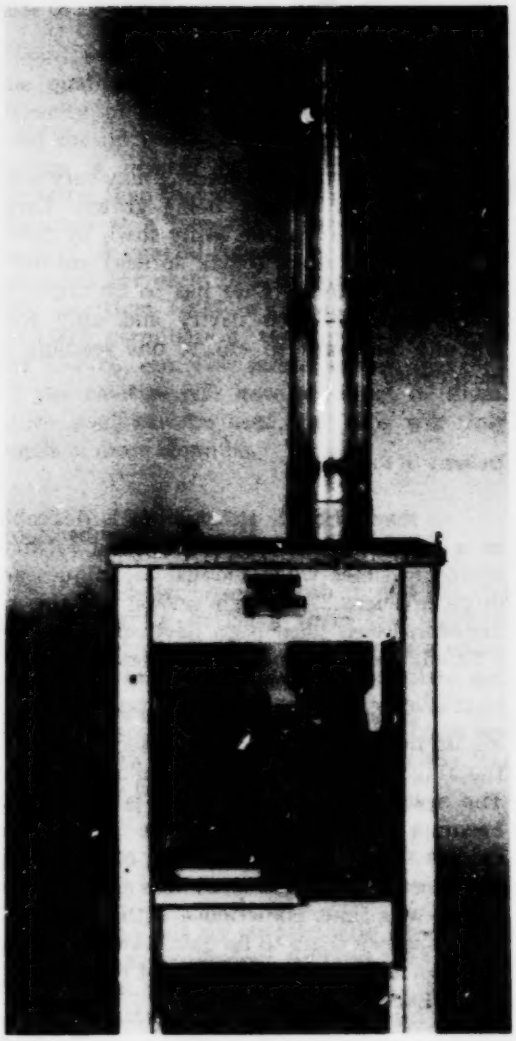

Fig. 8. South Dakota seed cleaner and separator.

Other preseeding treatments, such as hydrogen peroxide (H_2O_2) to disinfect seed or a fungicide for damping-off control, may be used where disease problems are likely to reduce germination and seedling vigor.

Stratification

Stratification is the storing of seeds in a moistened medium so as to maintain viability while overcoming dormancy (resting stage). Stratification procedures vary between species and may use acid, mechanical means, water soaking, cold treatment, heat treatment, or other chemical treatment. The two most common treatments used for conifers are cold and heat. The length of treatment again varies with the species, up to 4 months.

There are three important requirements for a good cold stratification: (1) moisture must be available, (2) near-freezing temperatures should be maintained, and (3) the seed should be adequately aerated. These conditions ensure biochemical activity in the seed and a minimum of microbial contamination. A good peat moss medium serves the purpose quite well. There are many ways of separating seeds and medium during stratification, but recently plastic bags have been used extensively. The plastic should be not thicker than 0.102 mm (4 mil) to allow oxygen to permeate for good aeration of the medium and seeds and yet restrict moisture loss.

Warm stratification is generally used in conjunction with cold stratification. The warm period in some cases helps the immature embryo to develop. Temperature should be constant somewhere between 12 and 30°C. The length of the treatment may extend up to 7 months depending on the species.

In the Prairie Provinces stratification of white spruce, jack pine, and lodgepole pine seed is not normally required. However, a cold, moist treatment of spruce seed in peat for 3 weeks in an ordinary refrigerator set at 4.5°C will ensure more uniform germination.

Disease Control

In bareroot nurseries, damping-off can cause up to 80% mortality if left unchecked. However, in a containerized seedling rearing program this disease is not much of a problem because of the acid medium used and the generally good sanitation practices around rearing facilities.

A more prevalent problem is fungi on the seed due to contamination during seed extraction or from poor storage conditions

that may hamper germination. When the germinant is weak, such universal contaminants as *Penicillium* or *Aspergillus* species may inhibit radicle development. It is necessary, therefore, to clean the seed before seeding to ensure maximum germination and seedling establishment.

Dazomet soil sterilant and fungicides such as captan and thiram control damping-off but have not proven effective in preventing the other fungal contaminants from developing. In addition, captan and thiram may inhibit germination or distort growth. The most effective means of removing the fungi is with an H_2O_2 treatment. The seeds to be treated are placed in a suitable container: a beaker for small lots or a plastic bucket for large ones. A 3% solution of H_2O_2 is poured over the seeds until they begin to float. They are allowed to soak for 15 min, but should be stirred frequently to ensure that all seeds are treated evenly. Because the mixture may rise in temperature to as high as 65°C, it should be handled with care. After treatment the excess H_2O_2 is poured off, and the seeds are rinsed with cool, clean tap water and then spread to dry for 1-2 h before using.

Miscellaneous

Some conifer seeds are the same color as the medium, which makes it difficult to see them after seeding. Treating the seeds with baby powder (talc) will make them more visible, helping to identify missed cavities and ensure 100% seeding.

Preparation of the Medium for Seeding

Careful filling of the cavities has been dealt with on page 18. There are several additional steps that should be taken before seeding. First, the medium should be saturated with water to last until after germination, because it is difficult to add water during this period. Secondly, a slight depression should be made in the medium to direct the seed to the center of the cavity during seeding. The depression can be made with the fingers, or air can be used to blow out the medium in a small area. In some systems the peat is filled only to within 5 mm of the top, leaving the sides of the cavities to act as a barrier to seed moving between cavities.

Methods of Seeding

The method of seeding may vary with the species of conifer being grown. Large seeds (red pine) can be easily sown by hand, whereas small seeds (black spruce) are difficult to manipulate. Care has to be taken to place seeds in each cavity and only that amount necessary to ensure one seedling in each cavity.

Delivery of the Seed

Even though automation is desirable in a containerized seedling rearing facility, there are times when manual techniques are more efficient. Although several systems of delivering seed have been developed, none is efficient enough to be used universally.

Hand seeding is done by simply picking up the required number of seeds between the fingers and depositing them in a cavity. The system is slow, but if it is sped up it becomes inaccurate. There are small hand seeders that contain up to 30 g of seeds that are released through a small hole either one or several at a time. Experience with these seeders has shown them to be quite variable; thus, they are not much more efficient than picking up the seed manually.

Another type of seeder uses a vacuum to hold single seeds over small holes in a template. When the vacuum is released the seeds drop into the cavities. If more than one seed per cavity is needed the operation is repeated. One drawback of the seeder is that the holes may become clogged with pitch from the seed, thus leaving some cavities empty. Therefore, the template must be cleaned frequently.

Another seeder can be made with two templates with holes offset so that the upper plate can be loaded with seed and then moved to match the holes in the lower plate. The seeds drop through into the cavities. The amount of seed dropping through can be regulated by the size of the holes in the templates.

Seeding Density

Seeding density depends directly on the quality of the seeds. If the germinative capacity of the seed is lower than 60% the seed should not be used. If a particular seed source is needed but has low germinative capacity, then that seed will yield more usable seedlings at a reasonable cost in a bareroot nursery. A general rule of thumb is to deposit one seed for each 10% of germination capacity less than 100%, e.g., one for seed with 90-100% germination, two for 80-90%, three for 70-80%, etc. This should ensure that 90% of the cavities will have seedlings in them. More seed can be used, but this will only result in more thinning.

Postseeding Treatments

Seeds are covered with granite grit and watered lightly to bring them into contact with the medium. Then the trays are either placed in the greenhouse for immediate germination and growth or in storage until there is rearing space. In either case the trays are covered with 4-mil plastic to prevent the loss of moisture from the peat.

Gritting

The seeds are covered with No. 2 granite grit or an equivalent to hold them down during germination. This also aids in orienting the germinating radicle. The amount of grit used may vary with the species, but is usually just enough to cover the seed. Granite grit or white sand (quartz) is preferable to other materials.

The grit should be washed or sifted before use to get rid of fine particles of granite, which may compact on the surface of the medium. Natural sands are not recommended for covering the seed because they may affect the pH of the medium. High pH sands reduce germination and favor damping-off fungi. The grit or covering material can be delivered by hand or with a special gritter, similar to a fertilizer spreader. The gritter may use only one size of grit; therefore, care should be taken not to jam the machine with larger material.

Plastic Covering

Covering the trays with plastic will keep the moisture in the medium, especially where there is no misting irrigation system, and slightly increase the temperature during germination. After the trays have been put on greenhouse benches and watered lightly, large sheets of clear 4-mil plastic are laid over them. The edges are tucked under the trays to prevent them from flapping around when the air conditioning is on. The length of time the covering is left on depends on the species, but it is removed when germination just begins.

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SEED GERMINATION

The first step in the process of germination is the uptake of water, or imbibition. The water is soaked up by the seed and enters the cells by osmosis. Some seeds may take up to 70% of their weight during this process.

Although swelling due to water uptake may be noticeable, the first real evidence of germination is the cracking of the seed coat and the emergence of the radicle, or root tip. When the root is established in the medium the hypocotyl and cotyledons are extended into the air (Fig. 9).

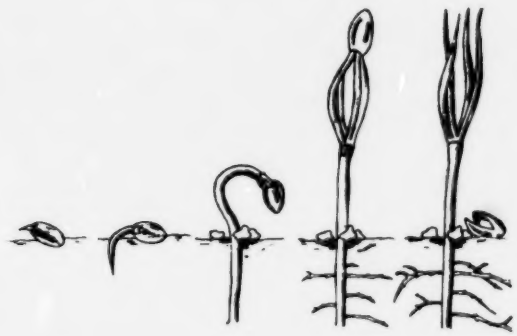

Fig. 9. Germination and emergence of a lodgepole pine seedling.

During a seed testing exercise the criterion for germination is that the radicle must be as long as the seed coat. However, during germination in the greenhouse, where seeds are covered with grit, germination is considered to have occurred when the seed coat containing the cotyledonary needles has been pushed through the grit and is visible—in other words, emergence.

Regulating Seed Germination

The effective regulation of seed germination does not necessarily mean inducing *rapid* germination. If germination is too rapid it may not be complete; this will result in fewer seedlings overall. Also, the speed and efficiency of germination vary between species; for example, white spruce will germinate in 8-10 d under ideal conditions, while lodgepole pine may take only 5-7 d. The main reason for regulating seed germination in a containerized seedling operation is to obtain a uniform crop.

Plastic Covering

The plastic covering, applied as explained in the preceeding section, serves two major purposes: (1) maintaining a high humidity around the seed and (2) slightly elevating the temperature near the seed. In a sense it is like using a hotbed for starting cabbage and tomato plants. If the plastic cover is too thick it is not easy to handle; if too thin it may tear and can't be reused. Therefore, 4-mil clear plastic is suggested for use in the greenhouse.

Temperature

Germination is considered to be an extension of regular growth. Therefore, with the exception of internal seedling dormancy, those temperatures that promote good growth usually promote good germination. Since the onset of germination is a physiological process (chemical activity), the warmer part of the temperature range for the species will bring about more rapid germination. When seeds are first harvested they respond only to a narrow range of temperatures. However, after storage the special temperature requirements tend to disappear. This response should not be confused with an internal dormancy, but should be referred to as "maturation". Day-night temperature requirements for germinating locally important conifers are all the same (Table 3).

Humidity

Relative humidity (RH) in the greenhouse should be kept between 90 and 100% during germination. This means frequent fine misting when plastic covers are not used to maintain a high humidity around the seed.

Table 3. Germination time and temperature requirements of selected conifer species[1]

Species	Germination time (d)	Temperatures Day (°C)	Night (°C)
Jack pine	5-10	30	20
Lodgepole pine	7-10	30	20
Red pine	10	30	20
White spruce	10-25	30	20
Black spruce	10-19	30	20
Colorado spruce	10	30	20
Douglas-fir	10-17	30	20

[1] Tables for other species can be found in *Seeds of woody plants in the United States*, U.S. Department of Agriculture, Agriculture Handbook 450. 883 pp.

Because frequent misting also cools the air and the seed and may therefore retard germination rather than aid it, the use of the plastic cover may be more effective.

Light

It is generally thought that exposure of imbibed seeds to red light will stimulate germination. In some container programs seeds are exposed to an 18-h photoperiod of 1.6 klx of incandescent light for 5 d before covering them with grit. This procedure is alright if proper stratification has not taken place, but will not increase germination of seed lots that already have a high germinative capacity. Seeds can be germinated in poor or no light, but the seedlings will soon become etiolated and chlorotic.

Use of Greenhouses and Growth Chambers

Germination usually takes place in the greenhouse, where the resultant seedlings are reared. However, special germinating chambers programmed to give proper light, relative humidity, and temperature may be used for small lots. Once controlled germination is completed, the seedlings can be put into a greenhouse for rearing. The use of growth chambers is generally considered too expensive for operational programs.

In certain situations seedlots with poor germinative capacities have to be used. This seed can be pregerminated in a germination cabinet, and only the good germinants transferred to cavities for rearing in the greenhouse. In this way a seed lot with only 20% germination can be used without loss of cavity spaces. Needless to say, this extra handling procedure can be expensive.

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THINNING AND DUDDING

Thinning and dudding seedlings in container systems becomes necessary when seed performance is variable and there is an excess or an absence of germinants in the cavities. Both processes are time-consuming and can be done only by hand. The seedlings are thinned to one per cavity to maximize the effect of container volume and nutrient regime. Germinated seedlings are placed into empty cavities to maximize use of bench space in the rearing facility.

Thinning

Timing of thinning is important. It should be done between the second and third weeks after seedling emergence. By this time the seed coat will be shed from the cotyledonary needles, and the more vigorous-looking seedlings in each cavity can be recognized

and saved. Thinning should not be delayed, because the seedlings quickly become anchored in the medium. Once they are anchored, removal will disrupt the roots of adjacent seedlings, causing shock or reducing vigor.

Thinning is a hand operation that requires the ability to recognize vigorous seedlings and to use tweezers or small scissors. The seedlings may be pulled out if there is little radicle development, but they have to be cut off if the roots are too solidly anchored. Some seedlings that are pulled are used in the dudding process; otherwise, they are discarded.

Dudding

Dudding, or filling empty cavities with germinated seedlings, is usually done at the same time as thinning. It should be done only to bring the cavity occupancy of a successfully germinated system up to 90-100%. If more than 40% of the cavities are empty they should be reseeded. In some container systems individual cavities or groups of cavities with vigorous seedlings can be grouped together, and the empty ones can be reseeded. However, other systems have large blocks of cavities in single units, and dudding is the only way to improve space usage. The individual grower has to make the decision whether to save, discard, reseed, or dud, depending on the value of the crop being reared.

Seedlings used for dudding may be obtained from the thinning process or from specially grown seedlings or germinants. The latter are preferred because they can be manipulated more easily. Seedlings pulled from thinned containers have long radicles and suffer from shock when transplanted. Pregerminated seedlings (radicle twice the length of the seed coat) can be placed in the container and covered with grit. Even though the germinants are about 2 weeks behind the other seedlings, they will not be as retarded in growth as those dudded from the thinning process.

GREENHOUSE CONDITIONS

Containerized seedlings develop rapidly between germination and removal from the greenhouse to the shadehouse for hardening. This is mainly in response to temperature, light, and moisture conditions surrounding the developing seedling. Other controlled environmental factors such as nutrition and irrigation will be covered separately.

Temperature

Biological and chemical activity increase as temperature increases to a point of optimum seedling growth; thereafter, increased temperature decreases the growth rate. The temperature limits for growth may vary slightly between species, but for practical reasons only the temperature effect on the growth of lodgepole and jack pine and white spruce will be discussed.

The optimum temperatures for growth of pine and spruce are 25 and 22°C respectively during the day and 16°C at night. Daytime temperature is more critical for white spruce (20-25°C) than for lodgepole pine (20-28°C). Because the optimum ranges overlap, both species can be grown in the same facility at the same time. Some other species, such as Colorado spruce, require a slightly higher night temperature (20°C) for optimum growth, but can still be grown successfully with lodgepole pine and white spruce.

A greater day-night temperature differential is required when seedlings are to be hardened. The lower night temperatures will stimulate root growth and slow top growth, thus making the tops more resistant to cold injury. Winter hardening in the greenhouse will require a gradual lowering of the temperature to near freezing over 4-6 weeks.

Day-night temperature regulation requires a dual thermostat controlled by a clock. The use of forced air heating is suggested because it responds more quickly to the heating and cooling requirements of the greenhouse.

Humidity

The regulation of humidity in the greenhouse is difficult in the prairies because

the surrounding atmosphere is generally dry, that is, less than 30% RH. The humidity increases quickly during irrigation but drops almost as quickly afterwards. Optimum RH for species grown in the prairies has not been determined; therefore, no attempt is made to regulate the humidity.

If humidity must be increased to reduce rapid drying of peat in containers, humidifiers, sprinklers, or swamp coolers can be used. Care must be taken not to maintain such a high humidity that fungal problems, especially grey (*Botrytis*) mold, will develop.

Containerized seedlings require low humidity for air-pruning of roots below the containers. Dry air stops the growth of roots between cavities and the matting of roots under trays. As the root tip egresses from the cavity it dries, and its growth is stopped. In most greenhouses the benches are constructed to allow air movement below the trays. The trays may be placed on racks made of wood or on benches made of expanded metal.

Light

The effect of light on tree seedling growth is a compound of several factors: photoperiod, intensity, and wavelength. The processes of photosynthesis and dormancy are affected by these factors plus the interaction of light with temperature, carbon dioxide content, and moisture. The extent of these interactions is best understood by reading textbooks on plant physiology.

Photoperiod

The growth of containerized conifer seedlings depends more on proper photoperiod than on any other factor that can be manipulated in the controlled environment. Dormancy and flushing are directly related to day length. If the photoperiod is not properly regulated growth may be arrested, and the seedling may return to a state of deep dormancy from which renewal of growth will be very difficult. Photoperiod requirement varies not only between conifer species but also within species according to the latitude of the seed source. However, for practical purposes, the required photoperiod for the growth of conifers should be set at a minimum of 18 h. This will maintain continuous growth for species such as white and Colorado spruce, and intermittent growth for pine species. When seedlings are being hardened, the day length should be gradually decreased to 12-14 h. This is difficult in the spring, when the hardening process will have to rely more on changes in day-night temperatures. Spruce species seem to be more sensitive to photoperiod than pine species are. In some cases it has taken one growing season for containerized spruce to recover after being inadvertently put into dormancy by a photoperiod of 15 h or less.

Regulation of the photoperiod can be accomplished by using time clocks to control the lighting systems. The intensity of light needed for photoperiod extensions is about 1.6 klx. An innovation that extends the day length effect is the use of intermittent light during the dark period. Rather than keeping lights on for the extra 4-10 h, they are put on for a total of 2 min out of every 30 min; 12 s every 6 min is equally effective. Again the light intensity should be about 1.6 klx.

Light Intensity

The maintenance of accelerated growth requires a much higher light intensity than 1.6 klx. High light intensities are needed to promote photosynthesis, which results in increased growth. Intensities equal to 10-20% of full sunlight are considered sufficient for maximum photosynthetic activity (light saturation point). The light saturation point for most North American conifers is between 20 and 34 klx, but it can vary with age. Young needles may be saturated at 15 klx, whereas old needles of the same species do not become saturated until exposed to 30 klx.

High light intensity interacts with photoperiod to promote lateral branching in conifers. This is important in rearing containerized seedlings that are grown very close together. The shading effect of the upper needles reduces the light intensity on the lower needles and may restrict side branching of

such species as spruce. This phenomenon accounts for the better-branched seedlings grown in the summer when light intensities are extremely high.

Light intensities greater than the light saturation point can restrict growth, bleach seedlings of their essential chlorophyll, and if extreme, kill the seedlings. This can happen in nature at high altitudes.

Maintaining high light intensities under greenhouse conditions is quite expensive in terms of lighting fixtures and energy consumption. Since intensities as low as 7-14 klx can result in 75% photosynthetic efficiency, the use of a movable (travelling) high-intensity lighting system (high-pressure sodium lamp capable of up to 15 klx) may be a partial answer to the problem. The construction of the greenhouse facilities with high light-transmitting materials (glass) and proper placement of the greenhouse to intercept the maximum light (roof ridge lying in an east-west line) are two other parts of the solution.

Light Quality

Photosynthetic activity is greater at wavelengths of 620 and 440 nm (red and blue light). The new high-intensity discharge lamps (either high-pressure sodium or metal halide lamps) have the proper composition of light for photosynthesis. Standard fluorescent light, while rich in red light that satisfies photoperiod requirements, needs to be supplemented by incandescent light that supplies far-red light needed for photosynthesis.

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SEEDLING NUTRITION[4]

Seedling nutrition, the uptake and use of essential nutrient ions for seedling growth, is usually concerned with minerals that are derived from the soil. However, several elements required for growth are primarily derived from air and water: carbon (C) from carbon dioxide (CO_2), and hydrogen (H) and oxygen (O) from water (H_2O). The general structure of plants and their growth depend on the accumulation and utilization of these elements combined into carbohydrates (C, H, O combinations). These compounds store and supply great quantities of energy and, when combined with other elements from the soil, provide the basis for plant growth.

There is very little we can do to regulate the supply of C, H, and O except under controlled conditions, such as special growth chamber environments with enriched CO_2 or irrigation in the field. But we can control directly the other essential mineral ions that normally come from the soil. These minerals are divided into two classes: (1) major elements—those used in large amounts and (2) minor elements—those used in small or trace amounts.

The major elements are nitrogen (N), phosphorus (P), potassium (K), magnesium

[4] *This section written by I.K. Edwards.*

(Mg), calcium (Ca), and sulphur (S). Nitrogen compounds, needed in large amounts, form 40-50% of the dry matter of the plant cells (protoplasm); the plant cells also contain proteins, amino acids, and chlorophyll. Nitrogen is associated with rapid stem growth and green coloration. Phosphorus is involved in the transfer of energy throughout the vital growth processes in the plant. It is very important as a buffer in controlling acidity of the protoplasm and in root development and seed germination. Potassium, while not a constituent part of any plant structure, is found throughout the plant in large quantities. It is involved in starch formation and acts as a catalyst in the photosynthetic process. Its other activities are not clearly defined. Magnesium is essential for chlorophyll formation and forms a part of cell wall structures, as does Ca. Finally, S is utilized by the plant in the formation of essential organic compounds, proteins, and vitamins.

The essential minor elements are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl). All these elements are closely related to enzyme activity either as catalysts or as constituent parts of enzymes. Enzymes function as critical aids to the growth process, from building structural compounds to breaking down others into waste products.

The availability of minerals to the plant is affected by many factors. Two important ones are hydrogen ion concentration (expressed as pH level) and cation exchange capacity (CEC) of the medium. The effect of the pH on nutrient element availability is shown in Fig. 10. CEC refers to the capacity of the medium to retain the minerals. If a large quantity of the minerals cannot be held for some time near the roots, less will be absorbed. The higher the CEC, the more available the minerals will be for the roots. As with most good things there is a trade-off point. As the CEC increases, the structure of the medium becomes finer, causing problems with poor drainage and salt accumulation.

Factors external to the soil, particularly temperature and light, also play an important part in nutrient uptake.

Fertilizer Regimes

When a fertilizer regime is being set up, the interactions of external factors such as light and temperature on growth, in addition to variations in the growing cycle, greenhouse and shadehouse conditions, and species differences must all be considered. The ideal is to find as many compatible combinations as possible to reduce the work and cost of the operational routine.

During germination the seed endosperm supplies sufficient P and other essential elements; therefore, additions are unnecessary. The new seedling actually takes up few nutrients other than C, H, and O from outside the endosperm until 10-14 d after germination. Between the 4th and 16th weeks the seedling requires a regular supply of N-P-K, with the N and K making up the major portion. This is a period of rapid growth that can be maintained by proper light and temperature and a continued supply of N-P-K. At the same time, the minor elements are also needed to enhance growth and structural development. After 16 weeks the top growth of the seedling may be "shut down" at will by withdrawing the N and maintaining high levels of P and K. This allows for greater root development and affords the seedling some drought and frost resistance. Nutrient manipulation has to be coordinated with reduced light (intensity and photoperiod) and temperatures. If these conditions are carefully regulated, growth can be brought to a standstill and seedlings put into dormancy. Different species may require somewhat different regimes. Spruce tends to use less N than pine, and as mentioned, is more sensitive to photoperiod.

Recommended nutrient regimes for optimum growth of containerized conifer seedlings in the Prairie Provinces are given in Table 4.

Manual Fertilizer Application

The simplest application method is to mix each batch of required fertilizer in a

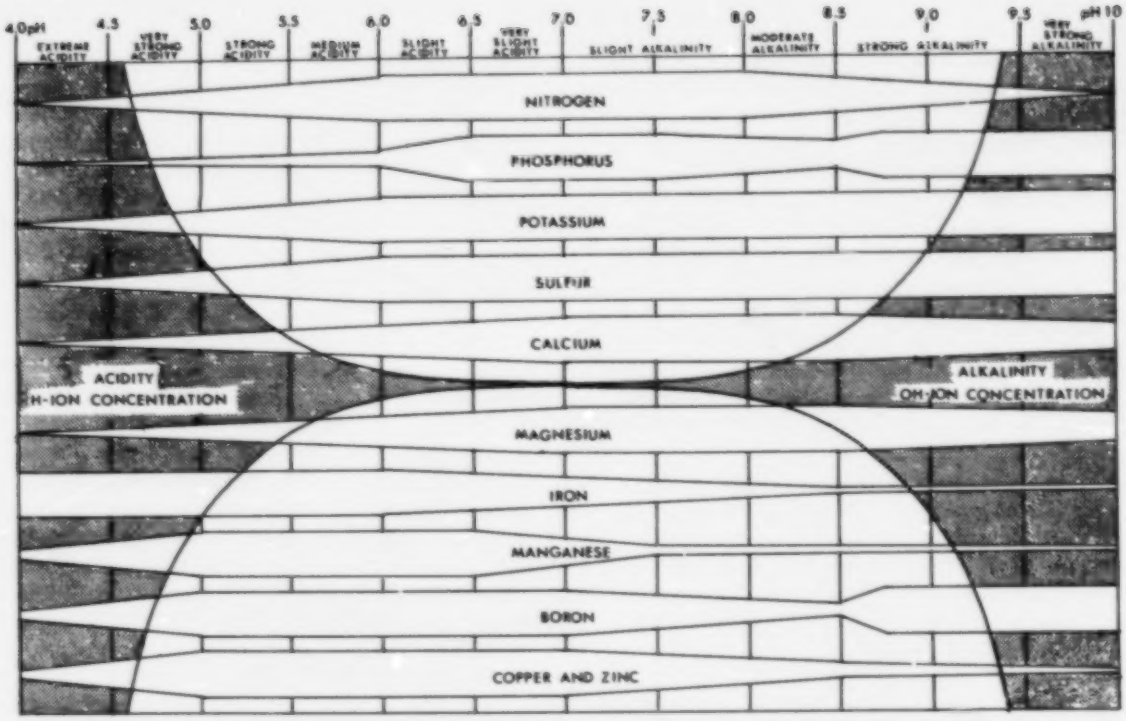

Fig. 10. Effect of hydrogen ion concentration (pH) on nutrient element availability (after Truog 1961).

watering can and apply it to the seedlings. This is handy if you have no more than 5000 seedlings to look after. However, even modest operational programs involve 10 000-20 000 seedlings, and so this method is somewhat time consuming, yet the size of the operation does not justify the expense of a sophisticated automatic system. This number of seedlings can best be fertilized by a modified hand watering system using a small water pump mounted on a 200-L (44-gal) drum connected to a watering wand. The nutrient solution is mixed in the drum, the pH is adjusted to 6.0 by the addition of H_2SO_4, and the solution is fed to the seedlings. This method has been used successfully at the Northern Forest Research Centre and at field stations.

One of the problems with the manual method is uneven fertilizer application, varying with the person doing the work. Nutrient burns or deficiencies have occurred when the person applying the fertilizer has either hesitated or hurried in his routine. In all operations care must be taken that the procedures are followed rigorously.

Automatic Fertilizer Application

Once the rearing operation reaches crops over 200 000, manual application of fertilizer becomes an arduous chore. Whether or not an automatic system is economic depends on the value placed on the end product; this is a decision made by the user, not the grower. However, the type and effectiveness of an automatic system are of concern in rearing healthy, useful, containerized seedlings.

An automatic system of nutrient application should deliver the same amount of nutrients to each cavity to ensure a uniform crop. Therefore, it is of paramount importance to choose an irrigation system that will give uniform coverage. The system should also

Table 4. Recommended nutrient regimes (feed solutions)[1] for optimum growth of containerized conifer seedlings in the Prairie Provinces[2]

Species	Early growth stage (28-35 d) N-P-K (ppm)	Rapid growth stage (42-112 d) N-P-K (ppm)	Hardening stage (112 d +) N-P-K (ppm)
Jack and lodgepole pine	229-29-154	229-29-154	45-99-165 or 44-101-156
White, black, and Colorado spruce	112-55-156	112-55-156	45-99-165 or 44-101-156
Pine-spruce mixture	125-60-159	125-60-159	45-99-165 or 44-101-156
Douglas-fir[3]	62-141-52	100-44-82	62-141-52

[1] See the discussion on "Source of Nutrients" (page 32) for minor element concentrations in the fertilizer solutions. Note that concentrations of stock solutions (page 33) vary slightly from those of the recommended feed solutions.

[2] The fertilizers should be applied at weekly intervals to be most effective. These regimes may vary with the time of the year; e.g., the rapid growth regime should cease 6 weeks before the seedlings are expected to be in the final hardened or dormant state.

[3] Dolomitic lime may have to be mixed with the peat medium, but this will vary with the Ca content of the source and the water used for irrigation.

be able to deliver the volume of nutrient solution required to flush the medium.

Nutrient Flush

The growth of tree seedlings in containers and in the field depends on good drainage. If soil is water-soaked, minerals cannot move through it, nor can potentially toxic salts and organic wastes from the root systems be removed. The proper peat medium, if kept saturated, will allow these products to move out of the root zone. However, frequent but light applications of nutrient solutions do not move the accumulated "staling" products out of the medium. As these build up so does the pH, which limits the uptake of the nutrient salts and increases the stress on the plant.

This problem can be eliminated by (1) using only peat as a growing medium and (2) fertilizing once a week. Each week the containers should be literally "flushed" of the staling products with a large volume of nutrient solution (1 L per 100 40-cm^3 cavities). If wastes are not flushed out, the seedlings will respond rapidly with poor top growth and stunted root growth.

Don't make the error in thinking that a *large volume* of nutrient solution at a specific concentration gives the seedling more nutrients. The peat takes up only so much solution; the rest flows through, leaving only the added concentration surrounding the roots. The only way to increase the nutrients is to increase the concentration of the feed solution.

Foliage Rinse

If the applicator of the fertilizer hesitates in his routine, seedling foliage can be burned by certain fertilizers, particularly 0-0-62. It is a good practice to rinse the fertilizer solution off the needles immediately with a hand watering wand or with clean water through an automatic system for about 15-20 s.

Source of Nutrients

In early experiments on container seedling nutrition, the chemicals were obtained from local suppliers. Many of the chemicals were chloride salts such as $MgCl_2$, KCl, and $FeCl_2$, so the resultant fertilizer solutions were high in chlorides, which if not properly flushed caused serious salt injury. As well, the cost of reagent grade chemicals was prohibitive. This led to the use of commercial grade, total soluble fertilizers that are chloride free. These also contain minor elements that, in the fertilizer solutions, have the following concentration ranges: Fe, 0.121-0.657 ppm; Mn, 0.008-0.276 ppm; Cu, 0.009-0.277 ppm; Zn, 0.006-0.274 ppm; B, 0.016-0.230 ppm; and Mo, 0.002-0.007 ppm. Additional Fe is supplied in the form of iron chelate (10% Fe). Calcium, Mg, and S may be supplied in the fertilizer but are usually found in sufficient concentrations in groundwater.

Some prescriptions call for extra K, and care must be taken to use the purer form of 0-0-62 (KCl) that is white rather than the pink form. If there is a fear of high chlorides or low S, 0-0-50 (K_2SO_4) can be used, but it does not dissolve as readily as 0-0-62. Deficiencies in minor elements can be remedied by the use of additional chelated microelements, or where possible, by dolomitic lime. These additions should be made only after consulting with a soils specialist.

Specific Nutrient Prescriptions

Feed Solutions

A. Spruce fertilizer at 112-55-156 ppm N-P-K + 5.5 ppm Fe. Mix with tap water.

Commercial fertilizer	g per 50 L	g per 10 gal
20-0-25	22.0	20.0
10-52-10	12.1	11.0
0-0-62	4.4	4.0
Iron chelate (10% Fe)	2.7	2.5

B. Pine fertilizer at 229-29-154 ppm N-P-K + 5.5 ppm Fe. Mix with tap water.

Commercial fertilizer	g per 50 L	g per 10 gal
28-14-14	23.9	21.7
20-0-25	23.9	21.7
Iron chelate (10% Fe)	2.7	2.5

C. Combination crop of spruce and pine at 125-60-159 ppm N-P-K + 5.5 ppm Fe. Mix with tap water.

Commercial fertilizer	g per 50 L	g per 10 gal
20-0-25	24.7	22.5
10-52-10	13.2	12.0
0-0-62 (KCl)	3.3	3.0
or		
0-0-50 (K_2SO_4)	4.1	3.7
Iron chelate (10% Fe)	2.7	2.5

D. Hardening fertilizer at i) 45-99-165 ppm N-P-K + 5.5 ppm Fe or ii) 44-101-156 ppm N-P-K + 5.5 ppm Fe. Use warm (37-40°C) tap water.

Commercial fertilizer	g per 50 L	g per 10 gal
i) 9-45-15	25.0	22.7
0-0-62	10.0	9.1
Iron chelate (10% Fe)	2.7	2.5
or		
ii) 10-52-10	22.0	20.0
0-0-62	11.6	10.5
Iron chelate (10% Fe)	2.7	2.5

The nutrients are applied weekly at the rate of 1 L per hundred 40-cm^3 cavities. Prescriptions for other species of conifers should be obtained from a soils or nursery specialist at one of the regional laboratories of the Canadian Forestry Service.

Stock Solutions

Preparation of nutrient feed solutions A, B, C, and D poses no problems if the prescriptions, as given, are followed. Because of the large volume of nutrient solution required in many nurseries, however, nurserymen find it more convenient to prepare a concentrated stock solution and to dilute this solution automatically before applying it to the seedlings as a feed solution. A dilution ratio of 1 part stock solution to 200 parts tap water is most commonly used.

In preparing such concentrated stock solutions, precipitates may form as a result of incompatibility of the ingredients, and dilution of the solution can result in an inaccurate nutrient concentration in the feed solution. For example, one operational application of Feed Solution A as a stock solution resulted in the formation of a precipitate and in 40% less phosphorus than was required in the feed solution. Analysis showed that phosphorus lost from the solution was present in the precipitate.

Although each fertilizer by itself dissolved reasonably well, precipitation occurred when fertilizers were combined, especially at high concentrations (e.g., 200 times the strength of the feed solution). This was particularly evident in feed solutions A (20-0-25 with 10-52-10) and B (28-14-14 with 20-0-25). Some precipitation also occurred in Feed Solution D (10-52-10 with 0-0-62) using cold (15-17°C) water. Precipitation is undesirable because the resulting feed solution concentration is then inaccurate and precipitates may block orifices and nozzles of the irrigation system.

Prescriptions for the preparation of stock solutions A, B, C, and D are given below. The solutions are 200 times as strong as the feed solutions and must be diluted accordingly before use. Solubility of the fertilizers increases in warm water; warming is particularly effective in preparation of Stock Solution D. To avoid precipitation, use freshly prepared stock solutions.

A. Spruce fertilizer at 112-31-156 ppm N-P-K + 5.5 ppm Fe following dilution of stock solution 200 times with tap water.

Commercial fertilizer	g per L	g per gal
20-20-20	56.0	254.6
20-5-30	56.0	254.6
0-0-62	15.5	70.5
Iron chelate (10% Fe)	11.0	50.0

B. Pine fertilizer at 225-41-155 ppm N-P-K + 5.5 ppm Fe following dilution of stock solution 200 times with tap water.

Commercial fertilizer	g per L	g per gal
28-14-14	107.1	486.9
20-5-30	75.0	341.0
Iron chelate (10% Fe)	11.0	50.0

C. Combination crop of spruce and pine at 125-34-156 ppm N-P-K + 5.5 ppm Fe following dilution of stock solution 200 times with tap water.

Commercial fertilizer	g per L	g per gal
20-20-20	62.5	284.1
20-5-30	62.5	284.1
0-0-62	10.1	45.9
Iron chelate (10% Fe)	11.0	50.0

D. Stock solution for hardening at i) 45-99-165 ppm N-P-K + 5.5 ppm Fe or ii) 44-101-156 ppm N-P-K + 5.5 ppm Fe following dilution 200 times. Use warm (37-40°C) tap water to make stock solution.

Commercial fertilizer	g per L	g per gal
i) 9-45-15	100.0	454.6
0-0-62	40.0	181.8
Iron chelate (10% Fe)	11.0	50.0
or		
ii) 10-52-10	88.0	400.0
0-0-62	46.2	210.0
Iron chelate (10% Fe)	11.0	50.0

To calculate the percentage of N-P-K in commercial fertilizers and the concentration of N-P-K in solution, the following method should be used:

1. The formulation on fertilizer bags refers to the percentage content of N, P_2O_5, and K_2O. Thus, 28-14-14 indicates 28% N, 14% P_2O_5, and 14% K_2O. To calculate P and K content:

   $P = P_2O_5 \times 0.44 = 14 \times 0.44 = 6.16\%$
   $K = K_2O \times 0.83 = 14 \times 0.83 = 11.62\%$

   Thus 28-14-14 commercial fertilizer contains 28% N, 6.16% P, and 11.62% K.

2. To determine the concentration of any fertilizer in solution:

   5 g of fertilizer/1 gal of water
   = 5000 mg/4.546 L = 1100 mg/L
   or 1100 parts per million (ppm)

3. To determine N, P, and K concentration, multiply the total fertilizer concentration by the amount of each element present in the fertilizer. For a concentration of 1100 ppm using 28-14-14 commercial fertilizer

   N = %N x fertilizer ppm = 0.28 x 1100
   = 308 ppm
   P = %P x fertilizer ppm = 0.0616 x 1100
   = 68 ppm
   K = %K x fertilizer ppm = 0.1162 x 1100
   = 128 ppm

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IRRIGATION

Water and the Container Medium

Water composes the major part of living plants. It gives turgor to cells and carries the important mineral elements, and its two elemental components, H and O, are important in plant metabolism. Water is supplied in containerized systems through the growing medium (peat), which should have sufficient water-holding capacity to support plant growth between irrigations yet be porous enough to allow leaching of accumulated salts. Water availability is affected by the salinity of the medium and water conditions.

Water may be lost by evapotranspiration (evaporation from the peat and transpiration of plants). Evaporation of water from peat accounts for the major loss during germination and early growth of seedlings. This type of loss is critical because the surface of the peat may become hydrophobic (water-resistant) to the point that future irrigations will not properly wet the medium. Grit covering plus frequent misting during this stage are helpful in maintaining moisture. Once the seedling has a needle surface that covers the cavity area, evaporation is reduced, and transpiration losses increase. Because this loss involves water taken up by the roots, the medium tends to dry throughout. It is therefore necessary to use watering techniques that replenish the water supply. The container aids physically in water retention by not allowing free lateral drainage.

Excessive loss of water is obvious when a seedling wilts. Unfortunately, the visible wilting point of many conifer seedlings closely precedes death.

Measuring Medium Moisture

There are direct and indirect methods of measuring water retention; it is advisable to use the direct methods and just be aware of the indirect ones.

The two direct methods are (1) the use of a soil moisture tensiometer to measure soil suction or (2) weighing the medium to measure actual water loss or gain. Tensiometers used for measuring soil suction are standard equipment on large field irrigation projects, but have to be modified to be used in a container system. Because loss of water also means a loss in weight, weighing devices can be used on one or more trays of seedlings to indicate the water loss. As the scale moves up it can activate an irrigation system. Such systems can be very simple mechanical or sophisticated electronic ones, or weighing can be done merely by lifting the trays from different areas in the greenhouse and noting those areas needing water. One quickly gains a feel for differences in weight, and this direct involvement can be considered part of TLC.

Indirect methods use light energy and wind measurements as a measure of the potential evapotranspiration of the system. High readings indicate that watering is needed.

Water Source

Water used for irrigation of containerized seedlings may come from a local groundwater supply, runoff (local reservoirs), or other surface sources such as rivers and lakes. The water differs according to source and also to season. Therefore, water quality must be monitored several times a year. Analysis of water for its characteristics that affect plant growth are essential to good irrigation mangement. Table 5 shows the type of determinations that are made by a water analysis laboratory and their meaning.

The water supply must be sufficient to supply the amount of water needed over the growing season. If the source gives only 6000 m^3 of water per year when 10 000 m^3 are needed, then there will be obvious shortages that will affect seedling growth.

Modification of Water Quality

There are several ways to modify the quality of water used for irrigation. The one used most frequently is acidification, which is done by adding phosphoric or sulfuric acid. This is important for rearing conifer seedlings, because they grow better in strong to slightly acid conditions (pH 5.0-5.5). If the electrical conductivity (EC) of the water is high, acidification with H_2SO_4 is preferable because the SO_4 ion can be supplied more economically than the PO_4 ion of phosphoric acid.

Water must be deionized if the EC is high. This process is very expensive and has several drawbacks: it does not remove B or sodium (Na); it does remove Ca^{++} and Mg^{++}, which in many nutrient regimes are assumed to be supplied by the tap water; and it is corrosive to metals, especially the brass used in most irrigation systems.

Softening water is out of the question, because the essential nutrient ions Ca^{++} and Mg^{++} are replaced by the nonessential ion Na^{+}, which deteriorates the structure of the medium so that it drains poorly.

Frequency and Amount of Water Used

There are no foolproof systems to tell the nurseryman when to water. The automatic weighing devices weigh only one or a few trays of seedlings and if not properly placed will lead to underwatering in some parts of the greenhouse and overwatering in others. In the final analysis, the experienced greenhouseman *knows* when the seedlings need water. He lifts trays, feels the medium, looks at the temperature, and even takes some plugs out to inspect the moisture in the cavity. Fortunately, with a good peat there is no problem with overwatering in a normal

Table 5. Important water analyses and their meaning[1]

Analyses	Meaning
Electrical conductivity (EC) measures salt content of water (mS/cm)	under 0.75 - acceptable 0.75-3.0 - increasing salinity hazard 3.0+ - unsatisfactory
Boron (ppm)	under 0.5 - acceptable 0.5-2.0 - not for sensitive plants 4.0+ - unsatisfactory
Calcium and magnesium (meq/L)	needed in order to understand the magnitude of salinity problems
Chlorides (meq/L)	to check for possible toxicity
Carbonate and bicarbonate ions (meq/L)	if in excess, plants may become chlorotic
Nitrate nitrogen (ppm of N)	may affect N fertilization program
Sodium (meq/L)	needed in order to determine SAR
Sodium adsorption ratio (SAR)	$\frac{Na^{+}\ (meq/L)}{\sqrt{\left(\frac{Ca^{++}\ (meq/L) + Mg^{++}\ (meq/L)}{2}\right)}}$ SAR of <3 - acceptable 3-8 - marginal 8+ - unacceptable
Hydrogen ion concentration (pH)	over pH 8 or under pH 3 - unacceptable

[1] Adapted from University of California *Nursery management handbook* (Furato 1968) - Section VIII, AXT-323.

growing cycle. However, peat-vermiculite, peat-soil, or highly humified peat do not drain as efficiently as a good peat. Therefore, unless it is extremely hot and dry, it is recommended that the seedlings be watered only once a week. Moisture is supplied alternately during the week with the fertilizer. Using this type of schedule we have never observed any mortality due to drought in the greenhouse. The grower is cautioned not to let the medium dry out to the point where water in the medium is unavailable, for growth will then be interrupted and will not likely return to normal.

The amount of water used is not constant because of the environmental factors affecting evapotranspiration. Again, constant checks of the seedling plugs with consideration of the local environmental factors (e.g., temperature and wind if in a shadehouse) are needed. The amount of water loss is greater as seedlings get older and have more needles. Therefore, it is suggested that water and fertilizer solutions be applied to saturation. To achieve this consider applying 1 L (approximately 1 qt) of water to one hundred 40-cm^3 cavities (1 L water/4000 cm^3 of medium). Thus, a greenhouse with 400 000 seedlings will require approximately 4000 L (880 gal) of water per irrigation or nutrient application period.

Irrigation Systems

The main criterion in selecting and using any irrigation system is to ensure that each cavity receives an equal amount of water. Those systems that do not give even coverage should be avoided.

Manual Operations

The recommended 1 L of water can be applied to each hundred 40-cm^3 cavities exactly by using watering cans holding 8 L and being careful to water only 800 seedlings. This, of course, is ridiculous, as we have mentioned that with a good peat medium excess water flows through, presenting no problems, and the time consumed by this type of manual operation is unwarranted. Manual operations require considerable judgment by the personnel carrying out the operation, but saturation has to be achieved.

Automated Operations

Automation or semiautomation of irrigation systems can be achieved with several types of delivery systems. The automatic part may be monitored by soil moisture tensiometers or weighing devices as suggested previously. While these are potentially efficient, most nurserymen prefer to check their seedling crop regularly and personally program the "automatic" aids at their disposal.

Water can be delivered through standpipe irrigation systems, fixed overhead systems, movable overhead boom systems, or many variations of these. Each has its special uses. In windy areas, overhead mist irrigation in a shadehouse complex would not be as efficient as a standpipe system. The movable boom is excellent for permanent greenhouses, but is not as convenient for shadehouses. Each situation has to be evaluated, and the proper system designed accordingly.

Watering from below, which will give the most uniform water infiltration and distribution, is not practical. It also is expensive and does not solve problems of salt accumulation.

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HARDENING

Hardening of conifer seedlings means making them tolerant to adverse conditions encountered after planting. This differs from dormancy, which is a rest period in which the seedlings stop growth or development. Adverse conditions likely encountered are frost, drought, and sun scalding. The hardening process has to promote tolerance to these weather conditions plus ensure rapid seedling growth and response to seasonal changes. Frost tolerance, while protecting the seedling early in the season, will not help if the seedling starts a second flush and continues to grow vigorously late in the season. The hardening process has to be manipulated to

approximate the natural growing period for the best results.

A natural seedling in situ from germination goes through many hardening conditions in its first 3-4 years before it reaches the size of the typical containerized seedling. It is very susceptible to frost and drought during its first year of growth; in fact, it barely develops beyond the first needle stage. Regulation of hardening in nature is generally considered synonymous with dormancy. Cool, late summer nights and shorter day lengths are the main factors bringing about dormancy in nature. There are also interactions of soil nutrients and moisture that are not fully understood.

Artificial hardening regimes try to follow the natural course, which, however, is not infallible, as exemplified by mortality caused by either late spring or early fall frosts or drought.

In an artificial hardening regime, the seedlings' environment is manipulated prior to outplanting. Depending on the time of the year, this may occur in a shadehouse complex, in a greenhouse, or in a finely controlled environment chamber. The following sections will discuss the first two alternatives, because controlled environment chambers are not generally used operationally.

Shadehouse Hardening

Containerized conifer seedlings are grown in the greenhouse for a specific time period (42-84 d) or until the seedling has reached a prescribed size. In the greenhouse the environment is carefully controlled to maximize growth and protect the seedling from daily changes in temperature, moisture, and sunlight. Because the seedlings are tender and very susceptible to these changes, they should be moved to a semiprotected area—the shadehouse—for extension of growth and for hardening.

As its name implies, the shadehouse provides sufficient shade to prevent sun scalding and at the same time blocks the wind from dessicating the seedlings. The shadehouse generally offers no control over day-night temperatures or day length. However, moisture is controlled with an irrigation system similar to that used in the greenhouse.

Seedlings are put in the shadehouse for hardening only after there is minimum chance for frost injury. This will vary in different areas. In warmer climates such as southern Alberta, the seedlings may be brought outside in late April, but near Edmonton and Winnipeg, May 10-15 is the earliest they should be put out.

There are also restrictions on how late in the season seedlings should be put into the shadehouse. Seedlings should have between 28 and 42 d to harden before either outplanting or the onset of the overwinter period. The latter is hard to predict and will vary in different parts of the Prairies, as will the onset of a frost-free period. In Edmonton, seedlings should not be placed in the shadehouse for "natural" hardening before May 10 or after August 20. As a practical suggestion the greenhouse manager can use the map of Plant Hardiness Zones in the Prairie Provinces (Fig. 11) and add or subtract one week from the above dates for Edmonton for each zone. Edmonton is in Zone 3; therefore, in Zone 2 seedlings can be put out safely between May 17 and August 13, and in Zone 1 between May 24 and August 6.

After the containerized seedlings are put in the shadehouse area, the nutrient regime is altered to promote root growth and restrict top growth. This means the reduction of N and an increase of P and K (see page 32, Prescription D). The frequency of fertilizing can also be reduced to once every 2 weeks instead of weekly. Irrigations are carried out as needed.

It is important that any seedlings stored outside during the winter should be covered with snow to insulate them from the extreme cold. In areas where the snow cover is likely to melt periodically during winter, cover the first lasting snowfall with an insulating material such as straw, cardboard, or foam plastic. These artificial covers should be removed in the spring 6 weeks before the normal time other seedlings go to the shadehouse.

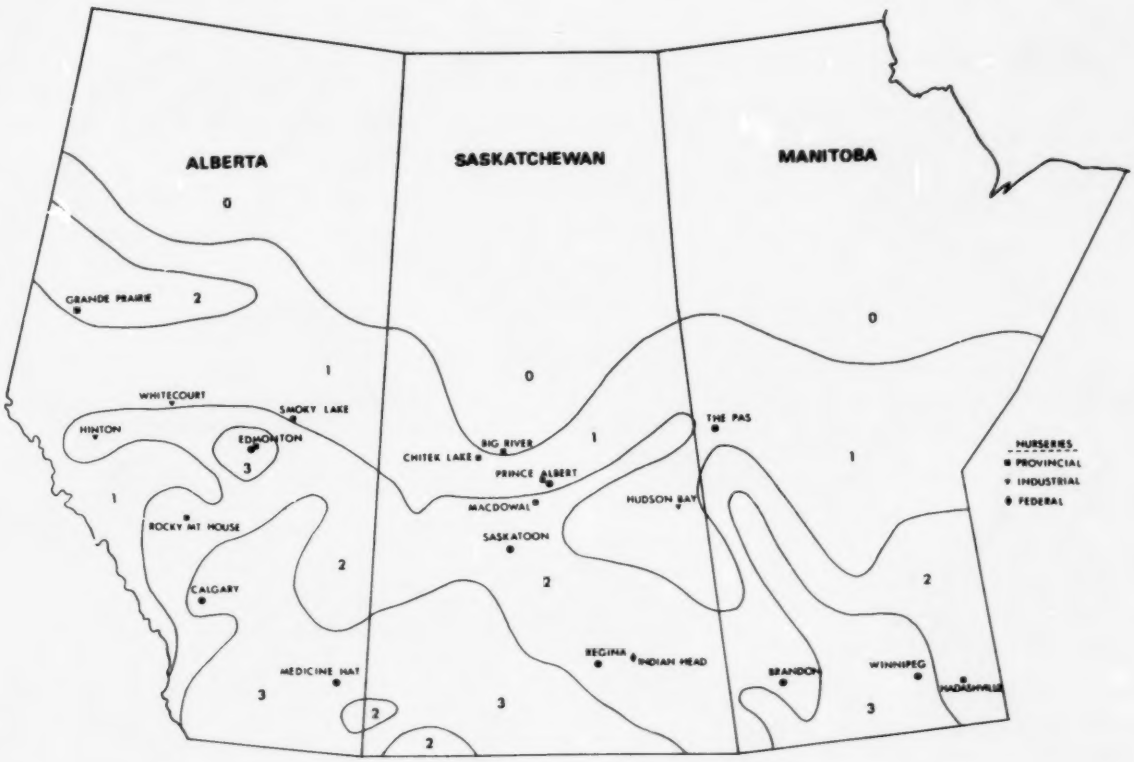

Fig. 11. Plant Hardiness Zones in the Prairie Provinces (after Ouellet and Sherk 1967).

Greenhouse Hardening (Winter Rearing)

The rearing of conifer seedlings in the greenhouse during late fall and early winter is attractive because it offers the grower an extra seedling crop during the year and also allows for year-round use of the facility. Unfortunately, the techniques for winter rearing, such as protecting seedlings from cold injury in very cold climates, have not been perfected. Some nurseries use root cellars for seedling storage, but very few actually put seedlings outside during January. This does not mean that it cannot be done, but each nursery will have to develop its own system. The use of root cellars or controlled temperature storage and putting seedlings out on warmer winter days and covering with snow as for fall storage (page 38) are two suggestions.

Before the seedlings are subjected to either cellar or outside storage they should be preconditioned for 6 weeks in the greenhouse. The temperature should be gradually lowered during that period to 2-5°C. The day length should be reduced to about 12 h to induce dormancy, especially for spruce. If there are no shades for reducing photoperiod, spruce should not be grown in the greenhouse after January 1, because under relatively warm temperatures (2-5°C) and increasing day lengths the species does not set buds properly. During the hardening period the watering and nutrient regime of the seedlings should be kept the same as during hardening in the shadehouse.

Despite the apparent advantage of having an extra crop a year, the grower has to weigh the cost of the energy used to produce the crop and the gamble taken where techniques are not proven. It may be wiser and cheaper to build extra facilities and have them closed down during the winter rather than to use extra energy by winter rearing.

Visual Signs in Hardened Seedlings

At present it is not possible to accurately assess the degree to which a seedling has been hardened and thus the certainty of its being able to survive and grow following outplanting. Determining the degree of hardiness is, to a large extent, part of the *art* of growing container seedlings. Fortunately, there are visual signs exhibited by some species that indicate their physiological state. Some seedlings change color when they become dormant. Jack pine and lodgepole pine turn dark green to purple and also produce a large terminal bud under average conditions. Spruce does not change in color, but it does normally set a terminal bud. Spruce can become dormant without bud formation, but breaking that dormancy usually requires a full year in the shadehouse. Pine may not form a bud but will readily start to grow when placed in warm, moist conditions.

The development of electronic equipment for determining dormancy or hardiness is progressing rapidly. These methods include water pressure measuring equipment (Scholander Bomb method), oscilloscopes, and other resistance measuring equipment. Once perfected, these methods will permit the grower to determine accurately the degree of hardiness attained.

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REARING SCHEDULES AND RECORD KEEPING

Rearing Schedules

There are many possible ways of combining the techniques previously described into quick, usable rearing schedules. Suggested rearing schedules for white spruce, jack pine, and lodgepole pine in three Plant Hardiness Zones located in the Prairie Provinces are provided in Tables 6-8. These are for greenhouse operations that will be using containers with cavity volumes between 35 and 88 cm^3; the schedules would have to be modified, particularly the extension of the true needle growth state, if the system uses larger-volume containers. *For each 100-cm^3 increase in cavity volume the true needle growth stage should be extended by 14 days.* It should be possible for the experienced production manager to extrapolate from the basic principles and specific information provided on these three species to determine the rearing schedules required to produce container seedlings of other conifer species.

Nursery Rearing Record

The quality of the end product of any system is judged by how well it measures up to the criteria set at the beginning of the process. The key is to measure the product to ensure that it stays at a consistent quality and to correct any lapses when they occur. This is the reason for a carefully conducted quality control program.

Containerized seedling quality control depends on maintaining good records on the

Table 6. Rearing schedules for white spruce, jack pine, and lodgepole pine in Plant Hardiness Zone No. 1 (Fig. 11), 2 crops per year

Date	Time (d)	Growth stage	Treatment phase[1]
CROP NO. 1			
Feb. 14	-1	pregermination	A - Hydrogen peroxide seed treatments
Feb. 15	0	germination	B - Seeding and gritting C - Cover with clear plastic D - Greenhouse temp. (max.)—30°C day, 20°C+ night E - Greenhouse light (min.)—1.6 klx, 18 h/d
Feb. 23	8	germination	F - Remove plastic cover (pine—day 5, spruce—day 8) G - Mist lightly H - Greenhouse temp. (±2°C): pine—25°C day, 16°C night; spruce—22°C day, 16°C night I - Greenhouse light (min.)—10 klx, 18-22 h/d
Feb. 23-Mar. 8	8-21	germination	J - Irrigate as needed
Mar. 8-Mar. 15	21-28	true needle	K - Thin seedlings to one per cavity J - Irrigate as needed
Mar. 15-May 24	28-98	true needle	L - Start fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 228-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed
May 24-July 5	98-140	hardening	M - Move seedlings to shadehouse J - Irrigate as needed N - Change fertilizer program to Prescription D (N-P-K at 44-101-156 ppm) for all species. Continue at 14-d intervals O - Protect from hard frost using irrigation systems J - Irrigate as needed
July 5+	140+	plant	P - Ship to planting site J - Irrigate as needed
OR			

Continued on next page.

[1] The pH of the medium should be checked every 4 weeks. Fertilizer prescription details are given on pages 32-34.

Table 6 continued.

Date	Time (d)	Growth stage	Treatment phase
July 5-Apr. 17	140-426	storage	N - Change fertilizer program to Prescription D (N-P-K at 44-101-156 ppm) for all species. Continue at 14-d intervals J - Irrigate as needed O - Protect from hard frost using irrigation systems Q - Cover after the first snowfall with straw, cardboard etc.
Apr. 17-May 8	426-447	storage	R - Remove straw, cardboard etc. J - Irrigate as needed
May 8+	447+	plant	L - Start fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 229-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals P - Ship to planting site J - Irrigate as needed
CROP NO. 2			
May 23	-1	pregermination	A - Hydrogen peroxide seed treatments
May 24	0	germination	B - Seeding and gritting C - Cover with clear plastic D - Greenhouse temp. (max.)—30°C day, 20°C+ night E - Greenhouse light (min.)—1.6 klx, 18 h/d
June 1	8	germination	F - Remove plastic cover (pine—day 5, spruce—day 8) G - Mist lightly H - Greenhouse temp. (±2°C): pine—25°C day, 16°C night; spruce—22°C day, 16°C night I - Greenhouse light (min.)—10 klx, 18-22 h/d
June 1-June 21	8-21	germination	J - Irrigate as needed
June 21-June 28	21-28	true needle	K - Thin seedlings to one per cavity J - Irrigate as needed

Continued on next page.

Table 6 concluded.

Date	Time (d)	Growth stage	Treatment phase
June 28-Aug. 6	28-74	true needle	L - Start fertilizer program using Prescription A (N-P-K at 12-55-156 ppm) for spruce, Prescription B (N-P-K at 229-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed
Aug. 6-Oct. 2	74-131	hardening	M - Move seedlings to shadehouse N - Change fertilizer program to Prescription D (N-P-K at 44-101-156 ppm) for all species. Continue at 14-d intervals O - Protect from hard frost using irrigation systems J - Irrigate as needed
Oct. 2-Apr. 17	131-328	storage	J - Irrigate as needed Q - Cover after the first lasting snowfall with straw, cardboard, etc.
Apr. 17-May 8	328-341	storage	R - Remove straw, cardboard etc. J - Irrigate as needed
May 8-June 5	341-377	true needle	L - Start fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 229-29-154 ppm) for pine, or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed O - Protect from hard frost using irrigation systems
June 5-June 19	377-391	hardening	S - Same as N at 7-d intervals J - Irrigate as needed O - Protect from hard frost using irrigation systems
June 19+	391+	plant	P - Ship to planting site J - Irrigate as needed

Table 7. Rearing schedules for white spruce, jack pine, and lodgepole pine in Plant Hardiness Zone No. 2 (Fig. 11), 2 crops per year

Date	Time (d)	Growth stage	Treatment phase[1]
CROP NO. 1			
Feb. 7	-1	pregermination	A - Hydrogen peroxide seed treatments
Feb. 8	0	germination	B - Seeding and gritting C - Cover with clear plastic D - Greenhouse temp. (max.)—30°C day, 20°C+ night E - Greenhouse light (min.)—1.6 klx, 18 h/d
Feb. 16	8	germination	F - Remove plastic cover (pine—day 5, spruce—day 8) G - Mist lightly H - Greenhouse temp. (±2°C): pine—25°C day, 16°C night; spruce—22°C day, 16°C night I - Greenhouse light (min.)—10 klx, 18-22 h/d
Feb. 16-Mar. 1	8-21	germination	J - Irrigate as needed
Mar. 1-Mar. 8	21-28	true needle	K - Thin seedlings to one per cavity J - Irrigate as needed
Mar. 8-May 17	28-98	true needle	L - Start fertilizer program using Prescription A (N-P-K at 112-54-156 ppm) for spruce, Prescription B (N-P-K at 229-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed
May 17-June 28	98-140	hardening	M - Move seedlings to shadehouse N - Change fertilizer program to Prescription D (N-P-K at 44-101-156 ppm) for all species. Continue at 14-d intervals O - Protect from hard frost using irrigation systems J - Irrigate as needed
June 28+	140+	plant	P - Ship to planting site J - Irrigate as needed
CROP NO. 2			
May 16	-1	pregermination	A - Hydrogen peroxide seed treatments

Continued on next page.

[1] The pH of the medium should be checked every 4 weeks. Fertilizer prescription details are given on pages 32-34.

Table 7 continued.

Date	Time (d)	Growth stage	Treatment phase
May 17	0	germination	B - Seeding and gritting C - Cover with clear plastic D - Greenhouse temp. (max.)—30°C day, 20°C+ night E - Greenhouse light (min.)—1.6 klx, 18 h/d
May 25	8	germination	F - Remove plastic cover (pine—day 5, spruce—day 8) G - Mist lightly H - Greenhouse temp. (±2°C): pine 25°C day, 16°C night; spruce—22°C day, 16°C night I - Greenhouse light (min.)—10 klx, 18-22 h/d
May 25-June 7	8-21	germination	J - Irrigate as needed
June 7-June 14	21-28	true needle	K - Thin seedlings to one per cavity J - Irrigate as needed
June 14-Aug. 13	28-88	true needle	L - Start fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 229-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed
Aug. 13-Oct. 2	88-138	hardening	M - Move seedlings to shadehouse N - Change fertilizer program to Prescription D (N-P-K at 44-101-156 ppm) for all species. Continue at 14-d intervals O - Protect from hard frost using irrigation systems J - Irrigate as needed
Oct. 2-Apr. 10	138-328	storage	J - Irrigate as needed Q - Cover after the first lasting snowfall with straw, cardboard etc.
Apr. 10-May 1	328-349	storage	R - Remove straw, cardboard etc. J - Irrigate as needed

Continued on next page.

Table 7 concluded.

Date	Time (d)	Growth stage	Treatment phase
May 1-May 15	349-363	true needle hardening	S - Same as N at 7-d intervals J - Irrigate as needed O - Protect from hard frost using irrigation systems
May 15+	363+	plant	P - Ship to planting site J - Irrigate as needed

Table 8. Rearing schedules for white spruce, jack pine, and lodgepole pine in Plant Hardiness Zone No. 3 (Fig. 11), 3 crops per year

Date	Time (d)	Growth stage	Treatment phase[1]
CROP NO. 1			
Jan. 31	-1	pregermination	A - Hydrogen peroxide seed treatments
Feb. 1	0	germination	B - Seeding and gritting C - Cover with clear plastic D - Greenhouse temp. (max.)—30°C day, 20°C+ night E - Greenhouse light (min.)—1.6 klx, 18 h/d
Feb. 9	8	germination	F - Remove plastic cover (pine—day 5, spruce—day 8) G - Mist lightly H - Greenhouse temp. (±2°C): pine—25°C day, 16°C night; spruce—22°C day, 16°C night I - Greenhouse light (min.)—10 klx, 18-22 h/d
Feb. 9-Feb. 22	8-21	germination	J - Irrigate as needed
Feb. 22-Mar. 1	21-28	true needle	K - Thin seedlings to one per cavity J - Irrigate as needed
Mar. 1-May 10	28-98	true needle	L - Start fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 228-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed

Continued on next page.

[1] The pH of the medium should be checked every 4 weeks. Fertilizer prescription details are given on pages 32-34.

Table 8 continued.

Date	Time (d)	Growth stage	Treatment phase
May 10-June 21	98-140	hardening	M - Move seedlings to shadehouse N - Change fertilizer program to Prescription D (N-P-K at 44-101-156 ppm) for all species. Continue at 14-d intervals O - Protect from hard frost using irrigation systems J - Irrigate as needed
June 21+	140+	plant	P - Ship to planting site J - Irrigate as needed
CROP NO. 2			
May 9	-1	pregermination	A - Hydrogen peroxide seed treatments
May 10	0	germination	B - Seeding and gritting C - Cover with clear plastic D - Greenhouse temp. (max.)—30°C day, 20°C+ night E - Greenhouse light (min.)—1.6 klx, 18 h/d
May 18	8	germination	F - Remove plastic cover (pine—day 5, spruce—day 8) G - Mist lightly H - Greenhouse temp. (±2°C): pine—25°C day, 16°C night; spruce—22°C day, 16°C night I - Greenhouse light (min.)—10 klx, 18-22 h/d
May 18-May 31	8-21	germination	J - Irrigate as needed
May 31-June 7	21-28	true needle	K - Thin seedlings to one per cavity J - Irrigate as needed
June 7-June 21	28-42	true needle	L - Start fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 229-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combintion of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed

Continued on next page.

Table 8 continued.

Date	Time (d)	Growth stage	Treatment phase
June 21-Aug. 20	42-102	true needle	M - Move seedlings to shadehouse L - Continue fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 229-29-254 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed
Aug. 20-Oct. 2	102-145	hardening	N - Change fertilizer program to Prescription D (N-P-K at 44-101-156 ppm) for all species. Continue at 14-d intervals O - Protect from hard frost using irrigation systems J - Irrigate as needed
Oct. 2-Apr. 3	145-328	storage	J - Irrigate as needed Q - Cover after the first lasting snowfall with straw, cardboard etc.
Apr. 3-Apr. 24	328-349	storage	R - Remove straw, cardboard etc. J - Irrigate as needed
Apr. 24+	349+	plant	L - Start fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 229-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals P - Ship to planting site J - Irrigate as needed
CROP NO. 3			
June 20	-1	pregermination	A - Hydrogen peroxide seed treatments
June 21	0	germination	B - Seeding and gritting C - Cover with clear plastic D - Greenhouse temp. (max.)—30°C day, 20°C+ night E - Greenhouse light (min.)—1.6 klx, 18 h/d

Continued on next page.

Table 8 continued.

Date	Time (d)	Growth stage	Treatment phase
June 29	8	germination	F - Remove plastic cover (pine—day 5, spruce—day 8) G - Mist lightly H - Greenhouse temp. (±2°C): pine—25°C day, 16°C night; spruce—22°C day, 16°C night I - Greenhouse light (min.): 10 klx, 18-22 h/d
June 29-July 12	8-21	germination	J - Irrigate as needed
July 12-July 19	21-28	true needle	K - Thin seedlings to one per cavity J - Irrigate as needed
July 19-Aug. 20	28-60	true needle	L - Start fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 229-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed
Aug. 20-Oct. 2	60-103	hardening	M - Move seedlings to shadehouse N - Change fertilizer program to Prescription D (N-P-K at 44-101-156 ppm) for all species. Continue at 14-d intervals O - Protect from hard frost using irrigation systems J - Irrigate as needed
Oct. 2-Apr. 3	103-286	storage	J - Irrigate as needed Q - Cover after the first lasting snowfall with straw, cardboard, etc.
Apr. 3-Apr. 24	286-307	storage	R - Remove straw, cardboard, etc. J - Irrigate as needed
Apr. 24-May 24	307-335	true needle	L - Start fertilizer program using Prescription A (N-P-K at 112-55-156 ppm) for spruce, Prescription B (N-P-K at 229-29-154 ppm) for pine or Prescription C (N-P-K at 125-60-159 ppm) for combination of spruce and pine. Continue fertilizer program at 7-d intervals J - Irrigate as needed O - Protect from hard frost using irrigation systems

Continued on next page.

Table 8 concluded.

Date	Time (d)	Growth stage	Treatment phase
May 24-June 5	335-349	true needle	J - Irrigate as needed S - Same as N at 7-d intervals
June 5+	349+	plant	P - Ship to planting site J - Irrigate as needed

development of the crop. Depending on the establishment and how refined it wants its records, an indexed card file or a sophisticated computer may be used to record data on seed sources, each crop (cross referenced to growing unit), and to some extent the fate of the crops. The first and last generally require the aid of outside agencies, but the information is necessary for crop history and improvement.

Rearing records should be easy to keep, yet informative. The best way is to keep the record with the crop so that an observation or treatment can be recorded almost immediately. Too often details are left to the end of the day (or sometimes the week), when they can't be clearly recalled. Each growing unit should have a handy place to store records. Some care should be taken to keep them from being excessively soiled, but at times a water-marked card is the best assurance that the information has been recorded in the growing unit.

There is a practical limit to the amount of information that can be stored on a working record form. The essentials of crop identity are species composition, seed source, growing units (greenhouses and shadehouses), dates started or moved, and quantity started. Quality monitoring requires information on seed germination, seedling inventory, seedling dry weight, bud development and shoot:root ratio, dates of watering and fertilizing, special treatments in the growing units, equipment failure, environmental variance, and pest problems (Fig. 12).

The size of the record form can be reduced if the record keeper uses abbreviations and characters to indicate the tasks that are completed or problems that have occurred.

Other Records

If analysis of the quality of production is to be complete there must be records of seed sources kept by the seed extraction manager and field records of plantation establishment followed up by the reforestation manager. Not only do these records have to be kept up, they have to be available for analysis by the rearing establishment in order to properly evaluate the effectiveness of rearing procedures.

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TROUBLESHOOTING AND REMEDY OF PROBLEMS

Most problems can be diagnosed by observing any abnormal conditions of the seed, seedbed medium, or seedling and by consulting the symptomology key (Table 9). The key will direct you to an index listing the cause of the problem and the pages of this manual on which corrective measures can be found (Table 10).

Following are two examples of how to use the key and index to diagnose and correct problems.

CONTAINER SEEDLING RECORD

Crop No. _____ Species _____ Seed source _____ Germ record _____
Greenhouse _____ Date in _____ Shadehouse _____ Date in _____
Trays seeded _____ Seedling/Tray _____ Total crop at 20 wk _____
Destination _____ Date & amount shipped _____

Week	Remarks	Week	Remarks
0		11	
1		12	
2		13	
3		14	
4		15	
5		16	
6		17	
7		18	
8		19	
9		20	
10		20+	

Side 1

Date of sampling for analysis : _____

Seedling No.	Root Dry Wt.	Shoot			Total Plant Dry Wt	Shoot Root Ratio (Dry Wts.)
		Dry Wt	Length	Bud State		
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
Total						
Mean						

Inventory Number of seedlings in trays Totals

1										
2										
3										
4										
5										
	5	10	15	20	25	30	35	40		

Avg. / Tray _____ No of trays _____

No of available seedlings _____

Side 2

Some suggested abbreviations:

Acid (<pH 7)	Ac
Alkaline (>pH 7)	Al
Black spruce	Bs
Damping off	Do
Douglas-fir	Df
Dudding	Du
Fertilizer	F
Fungus	f
Germination	G
Greenhouse	Gh
Gritting	Gr
Humidity	H
Irrigation	I
Jack pine	Jp
Light	L
Lodgepole pine	Lp
Neutral (pH 7)	N
Peat	P
Physical plant trouble	Ppt
Plastic cover	Pc
Seed	S
Shadehouse	Sh
Temperature	T
Thinning	Th
Trouble shooting	Ts
White spruce	Ws

For specific seedling problems see Table 9, page 52.

Fig. 12. Container seedling record form.

Table 9. Symptomology key for pinpointing problems encountered in rearing containerized seedlings

	Problem	Refer to*
1.	Seed or seedbed affected	2
	Seedlings affected	5
2.	Seed	3
	Seedbed	4
3.	Germination nil	F1b, M2, L3b
	Germination poor	F1a, M2
4.	Seedbed covered with algae	C4, E1a, M1
	Seedbed covered with fungi	A1b, G3
5.	Shoots affected	6
	Roots affected	30
6.	Stems	7
	Needles	11
7.	Stems deformed or flaccid	8
	Stems cut	10
8.	Stems deformed	9
	Stems flaccid	G1a, G1c
9.	Seedlings less than 2 weeks old	D2a, L3a
	Older seedlings	I2
10.	Tops present	C2
	Tops missing	H1, M3
11.	Cotyledonary needles	12
	True needles	16
12.	Needles deformed	13
	No deformation	15
13.	Needles fasciated or appear so	D2, M4
	Needles pinched to the tip with white tips	14
14.	Individual needles separate	F3
	Needles can't be separated	F2, L1, L2
15.	Needles yellowing or chlorotic	A1a, A2
	Needle tips white	D2, M4
16.	True needles deformed	L1, L2, M5
	No deformation	17

Continued on next page.

* Letter and numeral combinations are from Table 10, "Index to causes and remedy of problems ....", page 54.

Table 9 concluded.

Problem	Refer to
17. Uniform growth and development	18
Uneven growth and/or development	28
18. Seedlings chlorotic, yellow, or browning	19
Seedlings dark green or purple	27
19. Chlorosis general	20
Chlorosis restricted to new needles	B4a, B4b
20. Nutrition schedule followed regularly	21
Nutrition schedule not followed regularly	B1—B4
21. pH of peat medium above 7.0	A1b
pH not over 7.0	22
22. Seedlings in greenhouse	23
Seedlings in shadehouse or outside	25
23. Seedling browning	24
Seedling yellow only	A1b, A3a, E1b, L1, L2
24. Plants stand upright	G1b
Plants wilt before becoming brown	C3b, G2
25. Plants yellow only	A2b, A3a, E1b, L, L2
Plants browning in patches (showing mold)	26
Plants wilt and become pale in color	D1a
26. During first growing year	G2
During second growing year	G4, M6
27. Coloration occurs during growing period	B2a, B3a
Coloration occurs in shadehouse or in early fall (especially pines)	M7
28. Growth uneven but vigorous	29
Growth stagnated	E2a, C3, A3a
29. Uneven condition general in greenhouse	F
Uneven condition restricted	C1
30. Young seedlings (0-4 wk)	31
Older seedlings	32
31. Roots twisted and on surface of medium	L3a
Roots stunted and brown	A1a
32. Roots localized in medium	33
Roots throughout medium but growth poor	B, C3a, A3b
33. Roots only near walls of container	A3a, A3c
Roots only in the top portion of the container	A3c, C3b, C5

Table 10. Index to causes and remedy of problems encountered in rearing containerized seedlings

Cause	Remedy outlined on page
A. Medium	12
1. pH	12
a. low	
b. high	
2. Chemistry	12, 35
a. Na^+ content excessive	
b. Electrical conductivity too high (salts)	
3. Physical structure	12, 13, 18, 35
a. fine	
b. coarse	
c. compacted	
B. Nutrition	28, 40
1. Nitrogen (N)	31
a. deficient	
b. excess	
2. Phosphorus (P)	31
a. deficient	
3. Potassium (K)	31
a. deficient	
4. Minor elements	29, 32
a. Iron (Fe) deficient	
b. Zinc (Zn) deficient	
C. Irrigation	34
1. Uneven distribution	34
2. Water delivery too fast—splashing	
3. Frequency	35
a. too often	
b. too infrequent	
4. Dirty water	35
5. Not enough at one time	35, 37
D. Temperature	25, 26
1. Low	
a. frost	

Continued on next page.

Table 10 continued.

Cause	Remedy outlined on page
2. High	
a. greenhouse effect from plastic cover	
b. no shading in greenhouse	
E. Lights	27
1. Intensity	27
a. low	
b. high	
2. Photoperiod	27
a. short	
b. long	
F. Species Responses	18
1. Seed source	
a. cracked or immature seed	19
b. dormancy	19
2. Mutation (e.g., variegations)	
3. High resin content in seed coat	
G. Fungi	21, 27, 57
1. Damping-off	57
a. *Pythium*	
b. *Fusarium*	
c. *Rhizoctonia*	
2. *Botrytis* (grey mold)	27, 57
3. Saprophytes on medium	57
4. Snow mold	58
H. Insects	58
1. Chewing	
a. grasshoppers	58
b. others	
2. Sucking	58
L. Chemical contaminants	
1. Wood preservatives	57

Continued on next page.

Table 10 concluded.

Cause	Remedy outlined on page
2. Herbicides	57
3. Seed treatments	21, 57
a. fungicide	22
b. excessive preseeding treatment with H_2O_2	22
M. Miscellaneous	
1. Poor grit coverage	23
2. Germination environmental condition not met	24
3. Small mammals	58
4. Seed coat not removed	Brush off seed coats
5. Rapid growth	Check rearing schedules
6. Winter desiccation	37
7. Normal hardening process	37

Example 1

The following situation was noted in the shadehouse in mid-October. the true needles of jack pine seedlings were purple in color, growth was uniform, and there were no other apparent deformities. Start at entry 1—*Seedlings affected*, go to entry 5—*Shoots affected*, go to entry 6—*Needles*; go to entry 11—*True needles*; go to entry 16—*No deformation*; go to entry 17—*Uniform growth and development*; go to entry 18—*Seedlings purple*; go to entry 27—*Coloration occurs in shadehouse or in early fall (especially pines)*—see M7, which is in Table 10 (Index to causes and remedy of problems)—*Normal hardening process.* The coloration is due to hardening, and no corrective procedure is required.

Example 2

Identical symptoms to those outlined in Example 1 were observed except that the problem occurred during the growing period. Proceeding through the symptomology key (Table 9) you arrive at the same entry (27), but in this instance the *coloration occurs during growing period*, which directs you to B2a or B3a (Table 10). The problem is either a P or K deficiency; corrective procedures are outlined on page 31 and in treatment phase L of the rearing schedules, Tables 6, 7, and 8.

Specific Remedies for Fungal, Insect, and Small Mammal Problems

The correction of problems caused by fungi, insects, or small mammals depends on the agent causing the problem plus the restrictions in the application of chemical controls. Sanitation is the key to preventing the development of insect and disease problems. Correction of chemical contamination caused by insecticides, fungicides, herbicides, or wood preservatives is very difficult because it usually results in permanent damage or mortality. Therefore, this problem can best be controlled by avoiding the use of chemicals in the greenhouse.

Fungal Problems

Damping-off

Fungal damping-off of conifer seedlings in containers should be a rare problem. It will be encountered only when proper sanitation is not followed in the container loading and seeding area. The pathogens causing damping-off are primarily soil-borne and associated with soils from garden areas, particularly those with a pH over 6.5. In some nursery fields, chemicals are used to control damping-off, either as soil treatments or seed treatments. Generally, chemicals (fungicides) are not needed in containers using peat as a medium because the pH is sufficiently low to inhibit damping-off development.

Once damping-off has started little can be done to control it. The best treatment is to remove the medium and plant material from the greenhouse area. If damping-off is widespread there will usually be no recourse but to start all over, ensuring sanitary procedures in the headerhouse and using a peat with a pH between 4.5 and 5.5.

Botrytis (Grey Mold)

Grey mold of conifer seedlings can spread rapidly in the greenhouse or shadehouse if it is not checked. The disease is exacerbated by high humidity and warm temperatures. To control, lower the humidity, circulate the air, and use a fungicide such as captan (50% active ingredient) or thiram (75% active ingredient) at 2.4-3.6 g/L or benomyl at 1.2 g/L as a spray on the seedlings. If the disease recurs, the sprays may be applied weekly. Follow label instructions carefully for any pesticides.

Saprophytic Fungi

Generally saprophytic fungi are more annoying than dangerous to the containerized seedling, and no control measures are neces-

sary. However, there was one instance in which a fleshy fungal growth on the surface of the medium tended to crush the seedlings. The fungus, identified as *Pizisa trachycarpa* Curry, was found only in media with a pH over 7.0 and could not be transferred to media of lower pH values. If this fungus becomes a problem it is best to discard the contaminated medium and start over with the proper pH medium.

Snow Mold

Snow mold may be caused by several different fungi, but the control methods are the same. Fungicides with heavy metal components (e.g., mercury, chromium, and cadmium) have been used in the past, but they are now restricted or out of production. The problem can be reduced or eliminated in overwintered stock by protecting the seedlings from alternating freeze-thaw conditions in the spring. After the first lasting snowfall (December 1) cover the snow with cardboard or straw to prevent it from melting until late spring. This will prevent the build-up of an ice layer, which promotes the fungal growth over the plants.

Insect Problems

Insect control in the greenhouse situation is restricted to measures for spider mites and aphids. Acaricides such as aramite and tedion can be used for mites, and malathion for aphids. If the infestation of any insect is heavy, the use of fumigants is suggested. Insecticides and rates of application for controlling insects on woody plants in the greenhouse are given in Table 11.

In shadehouses or in the field shortly after planting, chewing by grasshoppers may considerably damage young conifer seedlings by either deforming or completely removing the top of the seedling. This problem occurs only where populations of the insect have been allowed to build up. Grasshopper populations can be held to a minimum around a nursery by adequate cultivation of the soil and proper crop rotation. Prevention of injury from grasshoppers at outplanting can be facilitated by planting only in freshly scarified areas. Grasshopper populations develop rapidly in scarified areas only during the second and third year after scarifying. Conifer seedlings are susceptible to injury only in the first year of outplanting. Overwintering of seedlings in the nursery also gives some protection.

Small Mammal Problems

Field mice and meadow mice may enter the greenhouse during the rearing period and eat the seed or damage young seedlings. However, they are more likely to be a problem outside in the shadehouse area in overwintered stock, where they nest in the lush needle growth under the snow and feed regularly on the seedlings. Occasionally larger mammals such as deer may enter the shadehouse area and browse, but adequate fencing should eliminate this problem.

Mice, ground squirrels, and possibly red squirrels should be eliminated from the conifer seedling rearing areas. They may be trapped effectively with live traps or snap traps. However, the use of poisoned bait is probably the cheapest and most effective way of eliminating them. Baits using strychnine and zinc phosphide work quite well. Mowing grass regularly and not allowing clumps of weeds to form and provide a nesting place will also reduce the rodent population around the greenhouse-shadehouse area.

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Table 11. Insecticides registered for controlling insects on woody plants in the greenhouse[1]

Insect	Insecticide	Dosage (active ingredient—a.i.) English measure (fluid ounces)	Metric
Aphids	diazinon	8 oz/100 gal	250 mL/500 L
	dichlorvos	20 oz/100 gal	625 mL/500 L
	oxydemeton-methyl	14.4 oz/100 gal	450 mL/500 L
	phosphamidon	9.28 oz/100 gal	290 mL/500 L
Mealy bugs Lace bugs	dichlorvos	0.225 oz/1000 ft^3	6.9 mL/100 m^3
	azinphos-methyl	0.22 oz/1000 ft^3	6.7 mL/100 m^3
	naled	0.86 oz/10 000 ft^3	25.9 mL/300 m^3
Leaf miners	lindane	1 smoke fumigator/10 000 ft^3	/300 m^3
		or 4 oz/100 gal	or 125 mL/500 L
	oxydemeton-methyl	8 oz/100 gal	250 mL/500 L
Mites	diazinon	8 oz/100 gal	250 mL/500 L
	dicofol	3.5-7 oz/100 gal	190-219 mL/500 L
	malathion	8 oz/100 gal	250 mL/500 L
	oxydemeton-methyl	8 oz/100 gal	250 mL/500 L
	phosphamidon	2 oz/100 gal	62.5 mL/500 L
Scales	malathion	10-20 oz/100 gal	312-625 mL/500 L
	mineral oil	8 oz/100 gal	250 mL/500 L
Thrips	diazinon	8 oz/100 gal	250 mL/500 L
	malathion	8 oz/100 gal	250 mL/500 L
	mineral oil	1.5 oz/1 gal	47 mL/5 L
	oxydemeton-methyl	8 oz/100 gal	250 mL/500 L
Greenhouse whitefly	diazinon	15 oz/100 gal	468 mL/500 L
	dichlorvos	20 oz/100 gal	625 mL/500 L
		or 1 smoke fumigator/10 000 ft^3	/300 m^3
	naled	1 smoke fumigator/10 000 ft^3	/300 m^3
	nicotine	12 oz/100 gal	375 mL/500 L

[1] Turn off mist systems; make sure blossoms and foliage are dry. Close windows and doors, lock entrances, and post warnings. Vacate premises. Spray foliage to run-off point, following label precautions carefully. Ventilate thoroughly before reentering 24-48 h after treatment. For mites repeat at 2-week intervals.

Peterson, G.W. and R.S. Smith, Jr. 1974. Forest nursery diseases in the United States. U.S. Department of Agriculture. Agriculture Handbook 470. 125 pp.

Stoeckeler, J.H. and P.E. Slabaugh. 1965. Conifer nursery practice in the prairie-plains. U.S. Department of Agriculture. Agriculture Handbook 279. 93 pp.

HANDLING AND SHIPPING

Seedlings must leave the nursery in good condition and well prepared for their journey to the planting site. Once the seedlings are reared, the trays will have to be moved to the shipping dock. This can be done by hand or by conveyer belts, rollers, or pallets. The terminal buds or growing portion of the seedlings must not be injured in transit. Once in place seedlings should not be disturbed.

Before shipment, the field staff receiving the seedlings should be notified of the impending arrival. In some cases it would be advisable for the responsible official in the field to become familiar with the nursery procedures before shipment in order to ensure continuity between the nursery and the field. Most importantly, the seedlings must be properly watered to withstand the journey to the planting site.

The seedlings may either be shipped in the trays they were grown in or extracted and packed for shipment. Handling procedures at the nursery are at a minimum in the former method, but space consideration plus the environmental aspects of container waste may favor the latter. Shipping in trays requires that the same tray return to the nursery or become a waste problem in the field. In some systems the container is not returnable, but in all systems the tray is reusable. The economics of transferring trays to and from the planting sites compared to packing and shipping from the nursery have not been investigated for all systems.

Because the root plug holds together once extracted, the packing program is similar to the bareroot operation; the seedling can be packed in boxes or wrapped in special packets sized for efficient use by the field planting crews.

The actual shipment of the seedlings should be in a refrigerated truck to guard against excessive drying and heat exposure. Seedlings shipped in the back of pickup trucks should be protected from the wind and sun during transit with a tarp or a camping shell. Once the truck has stopped, these seedlings should be removed to a protected area near the planting site.

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Tinus, R.W., W.I. Stein, and W.E. Balmer. (Eds.). 1974. Proceedings of the North American containerized forest tree seedling symposium, Denver, 1974. Great Plains Agricultural Council Publication No. 68. 458 pp.

PLANTING

All the care in the world is no good if the final stage of the process goes awry. Planting of the seedling constitutes the last handling by humans in the containerized seedling program. Presumably the next time human hands will come into contact with the tree will be when it is harvested. Because planting is so important, the resource manager should schedule special sessions to teach proper planting techniques to the planting crews.

Preplanting care is an extension of shipping and storage. Once the seedlings reach a general planting site they should be stored in a shady area that can be protected from rodents and other mammals and has ready access to water to keep the plugs moist. It is critical to keep the moisture regime in the containers optimum right up to planting. Seedlings under moisture stress are less likely to survive. Seedlings should be planted as soon as possible; if they are held for a long time, Murphy's Law ("If anything can go wrong, it will") will undoubtedly come into play.

There are many types of planting tools that can be used, including shovels

(spades), dibbles, bars, mattocks, and garden hoes. Special container plug planting tools have been developed, and depending on the type of soil in the planting areas, some work effectively. There are two types of recently developed hand-held tools, one that pushes the soil away and allows the seedling to drop into the hole (Pottiputki), and the other a motorized auger that digs a hole for the seedlings.

Planting machines that can be pulled behind tractors or crawler tractors have been developed, but their success is restricted by the terrain and the container configurations. The development of a good container planting machine is only a matter of time and the applied expertise of foresters and mechanical engineers.

Standard planting procedures used for bareroot seedlings can be used or modified slightly for container-grown conifer seedlings. It is essential that the seedling plug be placed upright and secured firmly. In heavy clay soils the peat plug may be forced out of the ground by frost. It is particularly important in these cases to use the type of plug that allows rapid root development into the surrounding soil. A poor interface between the peat plug and the surrounding soils will also interfere with the efficient uptake of moisture. The holes for the seedling plug must be the right depth. If too deep, air pockets form under the plug and may dry it out, and if too shallow, the plug sticks above the ground or the planter forces it into the hole and deforms the root system. Finally, it is important to cover the top of the peat plug with some soil to prevent the rapid evaporation of water. As the water evaporates the plug acts like a wick, and soon the entire root system in the plug is subject to moisture stress. Core-type dibbles are very useful because they allow the formation of a good plug-soil interface.

There are no postplanting treatments; however, some form of treatment may be required on particular occasions. Herbicides may be used to reduce the competition from weeds, and in particularly dry years fire pump irrigation may be needed to aid seedling establishment.

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Tinus, R.W., W.I. Stein, and W.E. Balmer. (Eds.). 1974. Proceedings of the North American containerized forest tree seedling symposium, Denver, 1974. Great Plains Agricultural Council Publication No. 68. 458 pp.

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APPENDIX 1

EXPLANATION OF UNITS USED[1]

Symbol	Name	Quantity Measured
^{o}C	degree Celsius	temperature
cm; mm	centimetre; millimetre	length (1 cm = 0.39 in.)
d	day	time
dm^3	cubic decimetre	volume (1 dm^3 = 1 L)
g; mg	gram; milligram	mass (1 g = 0.04 oz)
h	hour	time
klx	kilolux	illuminance (1 klx = 92.85 foot candles)
L; mL	litre; millilitre	volume (1 L = 0.22 gal)
meq	milliequivalent	weight of a compound
min	minute	time
mS	millisiemens	electric conductance (1 mS = 0.001 mho)
ppm	part per million	amount of substance
s	second	time

[1] SI (metric) units, prefixes, and English equivalents are explained fully in the *Canadian metric practice guide* (Canadian Standards Association 1976).